Conversion of an inland water vessel to LNG fueled

EPS Kiel

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Examensarbete för ingenjörs (YH)-examen

Utbildningsprogrammet för produktionsekonomi

Vasa 2012

EXAMENSARBETE

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Titel: Conversion of an inland water vessel to LNG fueled

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Sammanfattning

På grund av stigande oljepriser och strängare restriktioner av utsläpp söker marin industrin efter alternativa bränslen. LNG är ett av de alternativen som kommit fram kraftigt under de senaste åren.

I detta arbete kommer vi att göra ett konverterings koncept för ett inlands fartyg, MS Otrate.
Konverteringen är från diesel till LNG drift. Vi kommer att fastställa den ekonomiska lönsamheten samt de tekniska komponenter som behövs för en konvertering.

Målet med detta projekt är att arbeta fram ett Koncept som senare skall god tjänas av klassificerings institutioner som Germanischer Lloyd (GL) och Zentralstelle Schiffsuntersuchungskommission (ZSUK).

Tekniken för att göra en konvertering finns redan på marknaden. Även logistiken för bränsle tillförsel finns det lösningar för. För MS Otharate skulle det även vara ekonomiskt lönsamt att göra en konvertering.

Language: EN Key words: LNG, Conversion, Inland water shipping

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Title: Conversion of an inland water vessel to LNG fueled

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Summary

Due to rising oil prices and emission regulation the maritime industy have been looking for an alternative fuel for crude oil and diesel. LNG is one of the alternatives that are under development at the moment.

The aim of this project is to prepare a conversion concept for the inland water vessels MS Otrate from diesel to LNG fueled operation as a case study. We will ascertain the commercial and technical feasibility and work towards an approval of concept by the regulatory bodies involved: the classification society Germanischer Lloyd (GL) and the flag state representative Zen- tralstelle Schiffsuntersuchungskommission (ZSUK).

The outcome of this project is that the technology and logistics for a conversion already exists. In this case its also economically feasible to do a conversion.

Language: EN Key words: LNG, Conversion, Inland water shipping

INNEHÅLL

FÖRTECKNING ÖVER BILAGOR

1 INLEDNING

På grund av stigande oljepriser samt ökade krav på utsläpp söker marinindustrin efter alternativa bränslen för drift och energiförbrukning ombord.

Detta examensarbete har gjorts vid University of Applied Sciences Kiel (FH Kiel) i Tyskland. Projektet var en del av European Project Semester 2012. Gruppen bestod av fyra studerande från Finland, Turkiet, Spanien och Tyskland.

2 PROJEKTPLANERING

Planeringen av projektet började den 1 mars. Under hela mars månad hade vi intensivkurser som hjälpte oss att komma igång med projektet.

2.1 Det ursprungliga projektet

Från början var det tänkt att vårt projekts mål skulle vara att hitta de tre bästa skeppen för konvertering till LNG-drift i centrala Europa.

Vi delade in projektet i tre mindre delar. Den första delen skulle vara att analysera marknaden samt teknologin i dagsläget. I detta skede analyserade vi vilka tekniker som fanns till förfogande i dagsläget, men gjorde även en analys över hur marknaden och flottan ser ut i centrala Europa.

När detta var gjort var vår plan att göra en uppskattad underhållsprofil, en uppskattad energiförbrukning och en investeringskalkyl för de olika skeppen. Efter detta skulle vi med hjälp av de resultat vi kommit fram till välja de tre bäst lämpade alternativen för konvertering till LNG drift.

Efter att vi valt de tre bästa alternativen skulle vi bygga upp ett koncept för dessa, konceptet skulle innehålla:

- underhållsprofil
- mekaniska komponenter
- infoblad

- investerings- och underhållskostnader
- hur logistiken för LNG skall byggas upp
- visualisering av konverteringen
- fördelar jämfört med nuvarande teknik.

Avslutningsvis var planen att vi skulle göra en presentation för möjliga kunder och intresserade. Denna skulle innehålla följande data:

- fördelar jämfört med nuvarande teknik.
- möjligheter på marknaden för LNG i Europa.
- nuvarande leveranskedja för LNG samt logistikkoncept.
- rekommendationer för vidare forskning.
- tekniska lösningar.

2.2 Det slutliga projektet

Andra veckan i april hade vi ”Mid-term presentation”. Efter presentationen hade vi första mötet med vårt företag. Fram till detta hade vi följt vår ursprungliga plan och gjort en marknadsanalys.

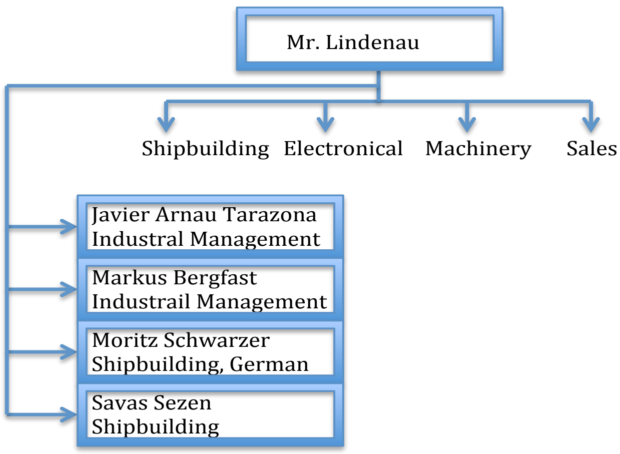
Under detta möte blev vi informerade om att Mr. Lindenau redan hade en färdig kund för en konvertering. Mr. Lindenau hade redan under en längre period arbetat självständigt på detta projekt. Detta betydde att vi inte längre skulle söka efter de tre bästa alternativen, utan att det redan fanns ett alternativ som vi skulle bygga upp ett koncept för.

Att bygga upp ett koncept för en konvertering av ett fartyg till LNG är inte lätt. Det finns ingen färdig logistik för bränsletillförsel och inga klara reglementen som bör följas osv.

Det som var bra var att vi alla hade hunnit få inblick i ämnet från marknadsanalysen som vi gjort tidigare. Vi behövde inte heller ändra mycket på den ursprungliga projektplanen. Skillnaden var att istället för att välja de tre bästa skeppen, skulle vi bara bygga upp ett koncept för ett skepp.

2.2 Projektorganisation

Vår kund är Lindenau Maritime Industry Consultants. Företaget är ett konsultföretag som specialiserat sig på den marina industrin. Vår kontakt person var Mr. Dirk Lindenau som var företagets VD. Figuren nedan visar hur vi integrerat oss i företaget. Vi arbetade enligt en matrisorganisation. Vi valde Moritz Schwartzer till projektledare, eftersom han hade mest erfarenhet inom marinindustri och talade tyska. Det kändes som den logiska lösningen.



Figur 1. Projekt organisation

En person som borde tilläggas i denna bild är professor Andreas Meyer-Bohe, som var ansvarig lärare vid skolan och gav oss massor av råd.

2.3 Mål och omfattning

Vi har delat upp våra mål och omfattningen av dessa i olika kategorier som man kan se i figur 2. ”The process part” beskriver vilka metoder vi skall använda för att nå våra resultat ”results”. I den sista kolumnen har vi det så kallade ”off scope”, som beskriver vad kunden kan ha för nytta av de resultat vi kommer till.

Process	Results	Usage of customer
Market and technology study	LNG Technology in River ships	Found ?
Analysing LNG Technology study	Three best practise examples	Article ?
Analysing Three best Ship types	Advantages of different propulsion	New Markets ?
	Market potential	Future fields of reasetch
Summary	Report	

Figur 2. Mål och omfattning

2.4 Projekt Plan

Vårt projektplan finns i bilaga 1. Som man ser på projektplanen har vi gjort några milstolpar och delat upp arbetstiden för varje del. I den ursprungliga planen var det tänkt att vi skulle träffas en gång i veckan för att diskutera med varandra hur arbetet framskrider. Var och en hade egna arbetspaket som man skulle jobba på individuellt.

Vi använde denna plan de två första månaderna av arbetet. Vi kom sedan fram till att det inte var produktivt. Då bestämde vi oss för att träffas åtminstone tre dagar i veckan för att arbeta hela dagen på projektet. Förutom våra egna möten hade vi varje vecka möte med Mr. Lindenau. Vid dessa möten gick vi igenom arbetet som blivit gjort under den senaste veckan samt att han gav oss information och nya idéer. Det var svårt att följa den ursprungliga planen. Men vi höll alla de tider som krävdes för de viktiga milstolparna. Projektplanen gav även en övergripande bild över vad vi skall ha gjort under en viss tid.

2.5 Fördelning av arbetsuppgifter (WBS)

Vi delade upp projektet i mindre delar, schemat kan ses i bilaga 2. Projektet är strukturerat i fem huvudgrenar som alla har ett flertal arbetspaket under sig. Samtliga i gruppen tilldelades arbetspaket som han var ansvarig för.

Ursprungligen var ledarskapsfördelning inom gruppen planerad så att vi alla skulle leda varsin del av projektet, som man kan se i bilaga 2. Moritz Schwarzer skulle vara ansvarig för projektplaneringen och en av delarna och resten av oss skulle vara ansvariga för en del. I praktiken slutade det med att jag hade ansvaret för att vi fick ihop en Mid-term rapport och Moritz Schwarzer ansvarade för slutrapporten.

2.6 Arbete inom teamet och utvärdering av arbetet

För de flesta av oss var det första gången vi jobbade i ett större team med ett projekt, framförallt ett interkulturellt sådant. Det medförde flera utmaningar. Arbetet kan ses i bilaga 3.

Ett av de största problemen vi hade i gruppen var kommunikationsproblem. Andra faktorer som påverkade vårt arbete var splittring inom gruppen, bristande ledarskap och olika kunskapsnivåer.

Vi hade en del problem med kommunikationen inom gruppen. Eftersom allt gick på engelska och vi hade en splittring i gruppen gällande språknivån som var mellan A2 och C2. Detta betydde att det var mycket utmanande att få alla att förstå uppgifterna samt att dela upp arbetet inom gruppen så att det skulle bli en jämn fördelning på arbetet.

Vi hade även en del problem med att komma överens i gruppen. Men det är omöjligt för fyra personer med olika bakgrund och kultur att ha samma åsikt om alla beslut som skall fattas. På denna punkt tycker jag personligen att det sköttes mycket professionellt. Då vi stötte på olikheter satte vi oss ner och diskuterade vilka möjligheter som fanns och tog sedan ett beslut som vi alla höll fast vid.

Vi märkte även hur svårt det kan vara att leda en grupp, speciellt i fråga om team där deltagarna är från olika delar av världen. Bara småsaker som att hålla tider och arbetstakt. Men även saker som skillnaden mellan hur man vill bli ledd var svårt. T.ex. i Turkiet föredrar man att bli ledd av en dominant ledare och respekten för ledaren är mycket stor. Jämfört med t.ex. Finland där det inte är vanligt att bli ledd med exakta instruktioner utan mera i form av problemlösning och eget ansvar. Vi noterade även att det kanske inte alltid är bäst att ha den som är ”specialist” på området att vara ledare.

Till min del av projektet hörde ekonomi, logistik, hållbarutveckling samt en del kalkyleringar av energi och förbränning, men även sammanställning och ledande av marknadsanalysen. Marknadsanalysen sammanställde vi till en Mid- term rapport som vi även presenterade.

Som tidigare sagt jobbade vi alla tillsammans största delen av tiden. Det gjorde vi för att alla skall veta hur projektet framskrider. Detta betyder också att man fick jobba med flera olika delar av projektet. Det är kanske inte det mest effektiva alternativet, men det fungerade. Man märkte även att det var först efter drygt två och en halv månad efter att vi hade haft vårt första möte som vår grupp blev riktigt produktiv. Man visste vad de andra i gruppen hade för kunskaper och hur de arbetar.

Det var planerat från början att vi skulle ha två personer som skulle vara insatta i fartygskonstruktion, men eftersom skolsystemet ser olika ut i olika länder hade inte en av fartygskonstruktörerna någon skolning inom området, eftersom han studerade första året på denna linje och under första året är det i stort sett endast språkkurser.

I slutet av projektet bestämde vi oss för att dela upp arbetet enligt följande: 23 % till mig, Javier Arnau Tarazona och Savas Sezen och de resterande 31 % till Mortiz Schwartser, eftersom han fått en del jobb som ingen av oss andra hade klarat av. Detta var exempelvis att läsa papper på tyska, använda marinaprogram som vi övriga inte kunde samt ha kontakt med de leverantörer som talade tyska.

3 MÖJLIGHETEN FÖR LNG I FINSKA FARVATTEN

Det finns stora möjligheter för LNG i framtiden i de finska farvattnen, eftersom miljökraven ökar konstant och industrin söker efter ett alternativt drivmedel på grund av oljepriset och den konstanta prisökningen. /1/

Internation marinetime organisation (IMO) som är den internationella sjöfarts-myndigheten, har olika program för att säkerställa kvalitet, säkerhet och hållbar-utveckling inom sjöfartsindustrin. Östersjön hör till ett kontrollområde där IMO försöker minimera luftföroreningar från fartyg. Till dessa utsläpp hör Sox, NOx och övriga partiklar. För att klara av de kommande reglementen är konvertering till LNG ett alternativ för att klara de nya standarderna. /1/

I Finland har LNG-forskning och utveckling kommit relativt långt. Det finns före-tag inom motortillverkning som t.ex. Wärtsilä OY som tillverkar motorer för drift med LNG. /2/

En av de saker som kommer att behöva utvecklas vidare är logistikkedjan för LNG, om detta skall bli ett fungerande alternativ för diesel. Det finns redan en LNG-terminal i Stockholms skärgård, men utvecklingen är bara i start skedet ännu. Viking Line kommer att utöka sin flotta med en färja mellan Åbo och Stockholm, M/S Viking Grace. M/S Viking Grace kommer att kunna köra på die-sel eller LNG./3//4/

LNG skulle vara ett attraktivt alternativ till de stigande oljepriserna och de höjda kraven på utsläppsminskningar. Flytande naturgas kommer med stor säkerhet att spela en stor roll i framtida marinindustri.

4 KÄLLOR

/1/ IMO hemsida,
http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Default.aspx (hämtat:12.8.2012)

/2/ Wärtsilä hemsida, http://www.wartsila.com/en/gas-systems/LNG-handling (hämtat:12.8.2012)

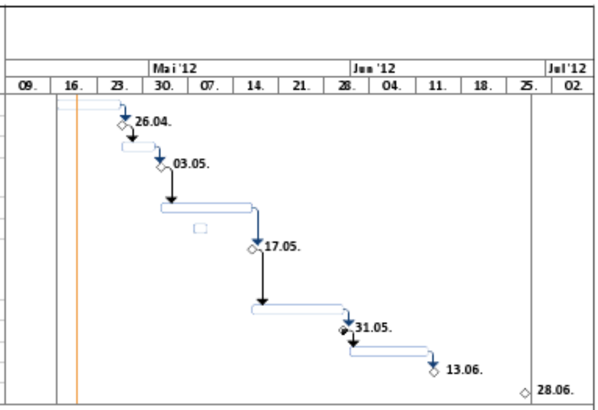
/3/ Trond Jerve, Stockholm Terminal, first LNG hub in the baltic sea, (Elektronisk publikation)
http://www.kmtp.lt/uploads/Renginiai/Klaipeda%20LNG%20Forum%202011%2006%2016/Stockholm%20Terminal%20%20TJerve.pdf (hämtat:12.8.2012)

/4/ Vikingline hemsida, http://www.vikingline.fi/onboard/newbuilding/ (hämtat:12.8.2012)

BILAGA 1

Project plan

Nr.		Vor	Vorgangsname	Dauer	Anfang	Fertig stellen
1			Market researtch	8 Tage	Di 17.04.12	Do 26.04.12
2			Team internal meeting	0 Tage	Do 26.04.12	Do 26.04.12
3			Analysing	3 Tage	Fr 27.04.12	Mi 02.05.12
4			Meeting LMIC 3 best choosen and approved	0 Tage	Do 03.05.12	Do 03.05.12
5			Concept 1/2	10 Tage	Do 03.05.12	Do 17.05.12
6			English courses (IDA weel	2 Tage	Di 08.05.12	Do 10.05.12
7			Meeting LMIC Mid-Concept development	0 Tage	Do 17.05.12	Do 17.05.12
8			Concept 2/2	10 Tage	Do 17.05.12	Do 31.05.12
9			Meeting LMIC Presenting	0 Tage	Do 31.05.12	Do 31.05.12
10			Finalising Report & prese	8 Tage	Fr 01.06.12	Mi 13.06.12
11			Final Report	0 Tage	Mi 13.06.12	Mi 13.06.12
12			Final Presentation	0 Tage	Do 28.06.12	Do 28.06.12



Projekt: LMIC
Datum: Fr 20.04.12

Vorgang
Unterbrechung
Meilenstein
Sammelvorgang
Projektsammelvorgang
Externe Vorgänge
Externer Meilenstein
Inaktiver Vorgang
Inaktiver Meilenstein
Inaktiver Sammelvorgang
Manueller Vorgang
Nur Dauer
Manueller Sammelrollup
Manueller Sammelvorgang
Nur Anfang
Nur Ende
Stichtag
In Arbeit

Seite 1

BILAGA 2

Workbreakdown structure

Work package name	WBS code	Inititials of responsible team member															
Project Management	**0**	**MS**	**Market Research**	**1**	**MB**	**Breakdown into shiptypes**	**2**	**JAT**	**Decision for best 3**	**3**	**SS**	**Concept development**	**4**	**MS**	**Report**	**5**	**tba**
Execution control	0.1	MS	LNG Technology	1.1	SS	rough Service profiles	2.1	MS	SWOT analysis	3.1	JAT	detailed Service profiles	4.1	MS	Development of document template	5.1	
tba		MS	Rivership fleet analysis	1.2	MS	Energy demand	2.1	SS	Development of scoring system	3.2	MB	Bloc diagrams	4.2	SS	collecting sub reports	5.2	
tba		MS	LNG market and supply chain	1.3	JAT	LNG supply concept	2.2	MB	fill out scoring spreadsheet	3.3	SS	Typesheet template	4.3	MS			
			Western Europe	1.3.1	MB	Components	2.3	MS	sub report 3	3.4	SS	Investment and operating cost, cash flow	4.4	JAT			
			Nort Eastern Europe	1.3.2	JAT	Cost	2.4	JAT				Supply concept	4.5	MB			
			South Eastern Europe	1.3.3	JAT	sub report 2	2.5	JAT				Sustainability of LNG rivership	4.6	SS			
			rules and regulations	1.4	MS							sub report 4	4.7	MS			
			Sustainability	1.5	MB												
			sub report 1	1.6	MB												

tba=too be anounced

BILAGA 3

Javier Arnau Tarazona, Markus Bergfast, Moritz Schwarzer and Savas Sezen

Conversion of an inland water vessel to LNG fueled operation

Final Report

EPS Programme Kiel, Germany, 2012

UNIVERSITY OF APPLIED SCIENCES KIEL
EPS Program Kiel, Germany 2012

ABSTRACT

Author	JAT, MB, MS & SS
Title	Conversion of an inland water vessel to LNG fueled operation
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Language	English
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Name of Supervisor	Andreas Meyer-Bohe

The aim of our EPS project is to prepare a conversion concept for the inland water vessels MS Otrate from diesel to LNG fueled operation as a case study. We will ascertain the commercial and technical feasibility and work towards an approval of concept by the regulatory bodies involved: the classification society Germanischer Lloyd (GL) and the flag state representative Zentralstelle Schiffsuntersuchungskommission (ZSUK).

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1. APPENDICES

2. FIGURES

3. TABLES

1 INTRODUCTION

This thesis is the result of one of four projects in the 2012 European project semester (EPS) at the University of Applied Sciences Kiel (FH Kiel) in Germany. Each project was done by a team of four international students from different parts of Europe with different technical and commercial backgrounds. Each project had an industry client that provided the topic for the project and a supervisor from the university.

Due to rising oil costs the energy costs have become the largest cost factor in shipping. Driven by the financial crisis the marine time industry is looking for ways to reduce those costs

The global climate change discussion has raised environmental concerns constantly higher in the awareness of customers and then Corporations. Legislation to reduce emissions and customers demanding ecologically produced and transported goods drive the shipping industry to look for ways to make their ships more sustainable. LNG is widely regarded as the alternative fuel for the shipping industry to achieve the emission reductions of the future while a rising oil price is expected to make it competitive to the established oil-based fuels.

The client for our project, Lindenau Maritime Industry Consultants, is a consulting company in Kiel, Germany that operates in the maritime industry with a special focus on sustainability. They have been working on LNG as a fuel for long before the EPS project. The introduction of LNG into the European inland water shipping industry has been one of the targets for LMIC. They have developed a network of suppliers for the mayor systems that we are going to use and together with the owner of an inland water ship have compiled a case study for the conversion of an inland water ship to LNG fuelled gas electric propulsion. This is the topic of this thesis.

This thesis is divided into three different parts. Firstly we will look at the market for LNG and river ships at the moment to get a status quo from where we can start our project. Then we develop a conversion concept for MS Otrate together with the suppliers. A first look into which regulations bear on our project follows, as a approval of concept by the classification society and the flagstate is the next logical step for after the project LMIC and MS Otrate. Finally we will look at investment and running cost for MS Otrate to determine the commercial viability.

1.1 The history of shipping

Maritime shipping dates back to at least 6500 BC. These first boats were canoes made from wood and driven by paddles. The first proof of what is considered advanced shipbuilding technology with ships powered by sails dates back to 2650 BC and the Egyptians. Next is the introduction of the steam engine to shipping in 1783. The steam engine is an external combustion engine, where a fluid is heated up to steam and then released trough pistons or turbines mechanical work is done.

The diesel engine, an internal combustion engine, replaced the steam engine after the Second World War. What can clearly be seen is that the times it took to get from one fuel to the next has always decreased. From human power, to wind, to coal and the oil-based fuels which are predominant today. Each change has allowed the shipping industry to grow and become more efficient. Due to the industrialization and development of engines shipping has had the possibility to grow and is and has always been one of the main transportation methods for humanity. But the use of fossil fuels has also led to the emission problem today, for which ships are one of the biggest causes today. /1/

1.2 Importance of shipping

To know how important shipping transport is in our lives, we should take a look at the diverse sorts of goods we are using every day. World trade brings us the computers, the clothes we wear and even the fuel that runs our cars. 90 per cent of those goods have been transported by ships or are made with parts transported by ships. /2/

Transport by ship is more favourable than other modes for several reasons, mainly for its lower cost, lower environmental impact and versatility.

1.2.1 Cost benefits

Transport by ship is in most cases more economically practical than shipping by air or ground. The decisive criteria are the distance to be bridged and the volume of the cargo. Depending from where to where the cargo has to be conveyed. Ships are the largest single units used to transport cargo. Following the logic of economy of scale, they can be regarded as the most efficient means to transport cargo, with the lowest maintenance and operation cost.

Shipping was established centuries ago, thus many ports have already been settled around the world and routes mapped for literally hundreds of years. Furthermore the acquired experience after centuries working in this form of transportation has gone a long way in improving methods, eliminating unnecessary expenses and raising the efficiency. /2/

1.2.2 Environmental impact

Ships have the lowest fuel consumption per tonne cargo carried and km distance. This also makes them the most environmentally friendly means of transport in terms of emissions per tonne and cargo. On the other hand the huge market share of shipping makes the industry also the biggest producer of emissions overall in the transport sector. /2/

1.2.3 Versatility

Sea faring cargo was always the most suitable form for conveying big volumes of cargo, bulk cargos like coal, raw materials, oil etc. The container has also made shipping the most suitable to convey large quantities of small goods over longer distances. Transporting goods by means of air or ground are only competitive when distance is comparatively small or the individual goods are slipt up into different directions for distribution. Cars, trucks, agricultural and industrial equipment as well as wide amounts of raw materials can all be shipped by sea individually; the rest fits into a container. /2/ /3/

1.3 Sustainability

Sustainability is one of the main focuses we have in our project; it can be defined as how we should meet the needs in our generation without compromising the needs of the future generations. /4/

Here are some examples on how to enhance sustainability every day:

- Carry a mug for coffee and tea rather than using disposable cups
- Use the backs of one-sided office paper for scratch pads and note pads
- Bring your lunch in a re-usable container
- Rely on natural light more often, especially if your lab, class or office has a window
- Walk, bike, carpool or take transit as often as possible
- Donate used clothing and other items instead of throwing them out.

Sustainability can be divided into three different aspects, environmental, social and economical. All three parts have to work in harmony to ensure a future for generations to come.

The number of regulations that govern the emission levels for countries and stakeholders is increasing. One the most known is the Kyoto protocol that was adopted in Kyoto, Japan 1997. The goal of the protocol is to reduce greenhouse gases in 37 industrialized countries. /5/ /6/

2 LNG

LNG is liquefied natural gas, a clear, colourless, non toxic liquid which is the result of cooling natural gas to below -162°C. This reduces the volume of the gas about 600 times. The challenge: the handling of the cold liquid.

Natural gas the biggest and still largely untapped source of energy around the world that is fully exploitable with today's technology. It is also the cleanest fossil fuel. Like oil, these reserves are far from the majority of consumers. Also as with oil, transport by pipeline requires high investment cost, large pieces of land and is not very flexible making it impractical for a lot of transport demands. As a result, the driving force to convert gas into LNG has been to make the storage and transport of natural gas to markets around the world more efficient. When LNG reaches its destination, it can be returned to gas in regasification plants for either immediate use or further distribution in pipelines. Or LNG can be stored as a liquid to be used as an alternative transportation fuel. /7/

The usage of LNG dates back to the 19th century. The German engineer Carl von Linde developed the basis for modern refrigeration technology, building the first practical compressor refrigeration machine in 1873. The first commercial gas liquefaction plant was built in Ohio in 1941. Nowadays, there are approximately 26 liquefaction and 60 re-gasification terminal all around the world. /8/

The consumption of LNG is on a constant rise. Countries like Norway, Qatar and USA are making significant investments in developing LNG technology. /9/

2.1 Technical facts

2.1.1 Composition of Natural Gas

Natural gas contains 87 – 96 % of Methane and between 1,5 - 5,1% of Ethane, also Carbon Dioxide, Mercury, Nitrogen, Benzene, Ethane, Propane, Butane, Pentane and other compounds can be found. The boiling point is -161.5 C, the freezing point of LNG is -182.5 C.

2.1.2 Liquefaction

Figure 1 shows the liquefaction process of natural gas. /10/

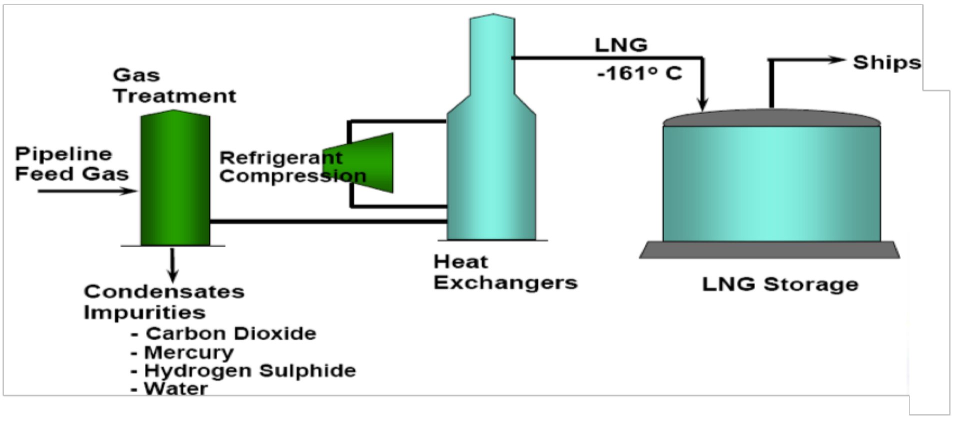

Figure 1, Liquefaction of natural gas

Liquefying of natural gas is a complex process, that is today done mostly close to the producing gas fields.

During the liquefaction of natural gas harmful compounds are subtracted and the long hydrocarbons are split. This enables LNG to burn very clean. /11/

2.1.3 Storage and transport

LNG is stored in special tanks for keeping the LNG at the very low temperature of -162 °C. LNG storage tanks can be found in ground, above ground or in LNG carriers. LNG storage tanks have a double shell, where the inner contains LNG and the outer container contains insulation materials. /12/

The large-scale transport of LNG is well established. Large LNG Carriers are used for ocean transport, typical size is about 150,000 t capacity, and new carriers are built up to 210,000 t. Three major types of tank design have been developed: /12/

- Spherical
- Membrane

- And Structural prismatic.

Small scale tanks are predominantly cylindrical tanks.

2.1.4 Safety

The industry of LNG is governed by risks and safety restrictions similar to any other industrial activity. LNG operators must submit to all national and local safety regulations and have done so since the beginning of LNG usage. Hazard mitigations must be carried out to reduce and ensure protection for surrounding communities and natural environment.

The only big LNG accident that involved population was in Cleveland, Ohio in 1944. This incident was a major push to improve safety standards. This has continued over the past four decades. The LNG industry has also demonstrated its high degree of safety of delivery at sea with more than 40 years of shipping LNG over the Atlantic, Pacific and Indian oceans with no major incidents implicating LNG carriers or their cargo. /13/

If LNG gets in contact with warmer air, it forms a white vapour cloud. As it continues to evaporate the gas which is lighter than air disperses in the atmosphere. Methane, the primary component of natural gas is only flammable if the mixing within 5-15 per cent methane to air.

If the mixture has less than 5 per cent, there will not be enough methane to burn. Equally, when there is more than 15, there is too much gas and not enough oxygen and the mixing will not burn. /14/ The mixture is from 0,6 to 8 per cent for gasoline and from 0,6 to 6 per cent for diesel.

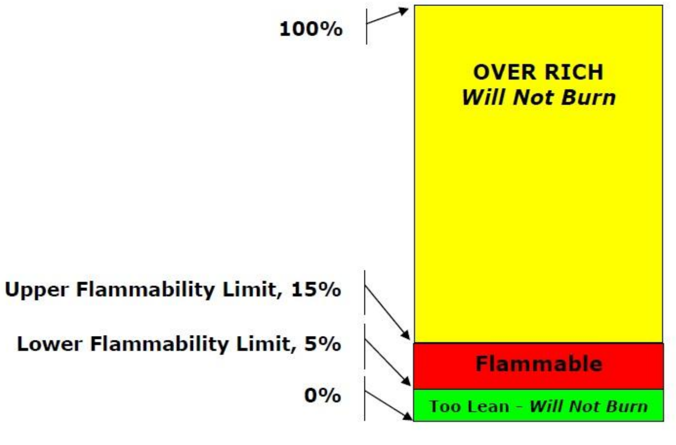

Figure 2, Flammable for Methane (LNG) /13/

To determine the fire end explosion hazard, the flame point and ignition point are the relevant criteria. The flash point of methane is -188 °C, but the range at which an ignition source can cause a flame is narrower and reached far later than with gasoline or diesel. If a gas leak is detected early enough, which is technologically feasible, ignition sources can be prevented before a flammable mixture is reached, which is not the case with gasoline or diesel which almost immediately form a flammable mixture.

The point at which a substance ignites without an ignition source just because of the surface temperature is called the ignition point. For methane this is 595°C. For gasoline it is between 200 and 410°C depending on composition and about 200°C for diesel. The surface temperatures encountered in a normal engine room make it highly unlikely that methane ignites by itself while a diesel or gasoline spillage will cause a fire much more easily./14/

2.1.5 Advantages and Disadvantages of LNG over Diesel

As seen on the table below we can see the energy content of Diesel, LNG and Gasolin.

Energy content	Diesel	LNG	Gasolin
MJ/Liter	36,4	25,3	34
MJ/KG	45,4	55	47,2

Table 1, energy content for Diesel, LNG and gasoline

Liquefied natural gas is a cleaner fuel than the established fuels for marine propulsion: diesel oil and heavy fuel oil. /15/

LNG has emission less over Diesel. SO_x and NO_x are reduced by more than 80 per cent and CO_2 among 15-25 per cent.

There is an increasing cost advantage over Diesel oil.

- Once the technology is beyond the initial adaption phase, operating and maintenance costs will be lower than Diesel oil.
- LNG is safer than diesel. In case of a leakage, the gas evaporates directly, due to the high-energy difference between room temperature and the liquid stage. The resulting mixture is not ignitable under atmospheric pressure. There is virtually no immediate damage to the en-

vironment. In comparison, Diesel is capable of burning and exploding in case of a spillage. Diesel also contaminates soil and water in case of a spillage

- Gas driven engines are less noisy than comparable conventional Diesel Engines

Disadvantages of LNG over Diesel:

- Currently the small scale logistic network needed is in the first steps of development
- Diesel oil can be stored in the ships structure (double bottom). LNG tanks are more complex; they are cylindrical and take up additional space on the ship. More tank volume is needed to contain the same amount energy.
- Investment costs are higher than Diesel. /16/

2.1.6 Difference between LNG and LPG

Liquefied natural gas consists mainly of methane. LNG has to be stored at -162°C for keeping it in its liquefied form and to keep it above atmospheric pressure. LPG is liquefied petroleum gas. It is a mixture of propane and butane that is stored in a pressurized container and also stored at room temperature. Butane and propane have a higher critical point, so pressurization is sufficient to liquefy the fuel. LNG needs to be refrigerated in a tank under the critical temperature of methane. In other words the temperature is important for LNG and the pressure for LPG. On the table 2 you can see the properties between the two kinds of fuels./17/

PROPERTIES	LNG	LPG
Toxic	No	No
Carcinogenic	No	No
Flammable vapour	Yes	Yes
Forms vapour clouds	Yes	Yes
Asphyxiant	Yes, only in a vapour cloud	Same as LNG
Extreme cold temperature	Yes	Only when it is refrigerated
Other health hazards	None	None

Flash point (°F)	-306	-156
Boiling point (°F)	-256	-44
Flammability range in air (%)	5-15	2.1-9.5
Stored pressure	Atmospheric	Pressurized (atmospheric when is cooled)
Behaviour if spilled	It evaporates forming visible clouds. Possibility of being flammable or explosive under certain conditions	Evaporates forming vapour clouds which could be flammable or explosive under certain conditions

Table2, Comparison of properties of LNG and LPG /3/

2.2 Market analysis

Today LNG is already well established for transporting natural gas across long distances because of the volume advantage of LNG over natural gas. Currently, LNG is then returned to gas state and injected into the established Natural Gas pipeline network for distribution and sales to the end customer. /18/, /19/

The usage of the natural gas in the different market sector is:

- 22% in the residential sector (heat and cool houses, cooking, water-heating)
- 14 % for the commercial sector (hospitals, schools, restaurants, office buildings)
- 32 % of the industrial sector´s energy needs (as fuel for paper, metal, chemical)
- 24 % of electricity generation (most of the plants around the world use natural gas because is cleaner for the environment than other burning fuels).
- 8 % for the transportation sector.

In the established Gas logistic chain, where LNG is regasified before local distribution, LNG transport only becomes favourable with distances of more than 3,000 kilometres. In this context, 60 % of the specific costs are attributed to the liquefaction. /20/

However, for the use as a fuel LNG needs to be distributed on a small scale. The regasification takes place at the end consumer, in our case on the individual ship. This logistic chain is currently under active development throughout Europe. One of our challenges is to bridge this distance between the established large scale LNG Network and our end customer with as few steps as possible.

2.2.1 LNG logistic chain

Figure 3 shows a likely value chain for small scale LNG distribution. It can vary depending on the exact location and demand.

Since no small-scale infrastructure is in place in Germany at the moment, our plan is to bridge the gap between the existing import terminals and the ship with LNG Containers, indicated in blue. These Containers can be transported in the established container logistic chain and also acts as the fuel tank on board. Thereby all links between the container logistic chain and the inland shipping network become LNG supply points. By using two smaller containers instead of one we are able to ensure a greater flexibility of operation.

Once the LNG logistic chain is sufficiently developed, the containers can remain on board and the ship can be refuelled by dedicated tanker trucks or at small terminals. Both types of supply can off course be combined just as needed.

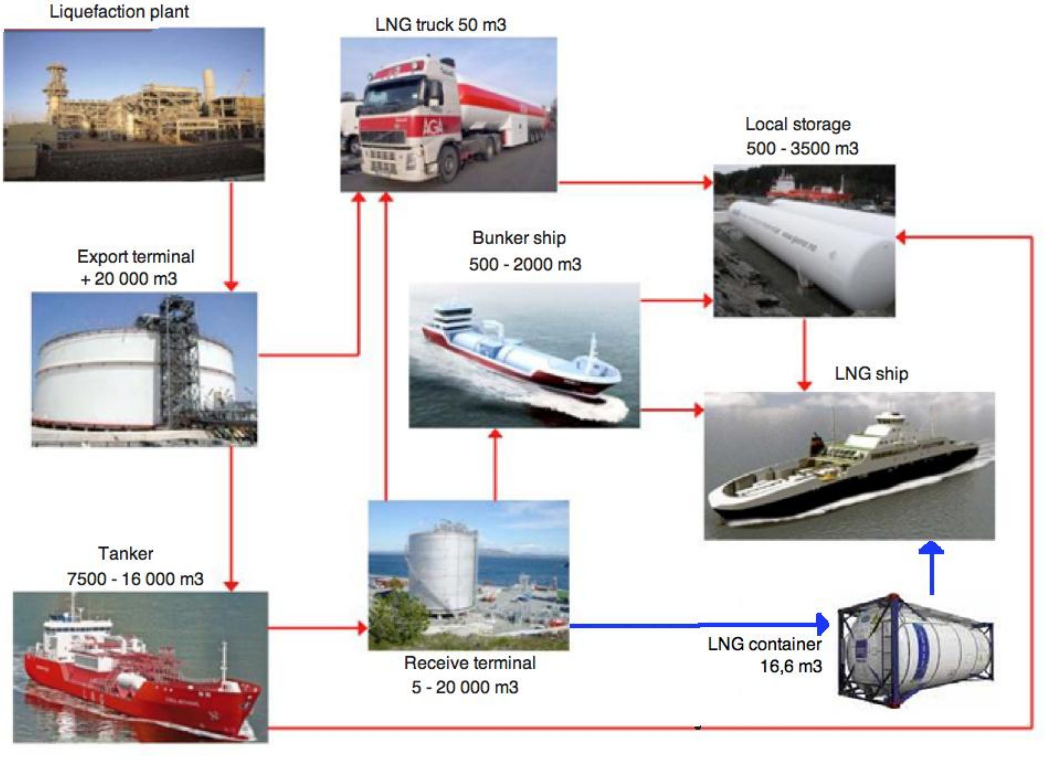

Figure 3, Likely value chain of small scale LNG distribution

2.2.2 How to get LNG in Germany

Currently, LNG is not widely used in Germany. There is an established pipeline network for natural gas dating back to the second oil crisis.

There are two possibilities for supplying LNG locally:

- A supply chain relying completely on LNG transport, that means distributing imported LNG that arrives on the coast in large LNG carriers to a network of sub terminals.
- Using the established natural gas pipeline network from Russia to run a small number of liquefaction plants on the mainland which then in turn feed a shorter small-scale distribution chain.

Currently, there is one liquefaction plant already operating in Southern Norway in the gas field Snohvit /21/. Norway has a strong LNG cluster, where a partial small-scale distribution is well developed and short sea shipping powered by LNG is already established. Snohvit is run by Statoil, the national Norwegian oil company, which has among others a long-term agreement with Dominion, the owner of the Cove point LNG terminal, Chesapeake Bay that secures a long term sales market. /22/

There is currently no agreement between Statoil and a possible German distributor, but this is a viable scenario for the future. Furthermore, Norway has established rules and regulations for using LNG that can be implemented without trial and error. However since the liquefaction process is complex and only economic at large scale, only justifying about one or two plants per country, the established Natural Gas network is not useful for providing LNG on a small scale. This option will not be considered

The LNG throughout supply scenario relies on a network of distribution terminals successively decreasing in size that are served by the large-scale import terminals on the coast.

By means of pumps and hoses LNG can be transferred into road trailers, barges and rail cars, or into Intermodal ISO containers for long time long, distance transport. This transport of LNG is similar to the established distribution of mineral oil products in individual tanks, be it by ship, truck or rail. /23/

Since the inland shipping market is small compared to road transport, the latter is more likely to be a driving force for the development of LNG Distribution. Frequently operated fleet vehicles such as Heavy-duty trucks, busses, municipal vehicles and taxis are typical vehicles with great potential for LNG fuelling. Compared to more traditional and in parts well established pressurised gas systems, LNG enables lower vehicle dead weight and longer runs because of its higher energy density. Centrifugal pumps ensure delivery of LNG into vehicles with the same speed, as high performance petrol pumps.

Figure 4, LNG suppliers in Europe /24/

2.2.3 LNG and LPG in the future

After the accidents at the Fukushima reactors in Japan, Germany has stopped the reconsidering the nuclear exit strategy already in place from previous administrations. Electricity distributors around the world announced plans to slow down or stop the development of new reactor projects. If nuclear energy is disappearing from the market, the world needs to find another way to produce energy. Natural gas is the only non-coal energy available right now that can provide electricity in the volumes needed at affordable prices, until renewable energy sources can cover the demand. Already, natural gas does not pollute the environment to the same extent as coal and does not generate solid waste. /25/

2.2.4 LNG as fuel in the future

Liquefied natural gas is expected to become the dominant fuel source for all merchant ships in this decade. Ships must cut emissions of sulphur oxides, from 4.5 per cent today to 0.5 by 2020 under rules from International Maritime Organization. In the Environmental Protection Zones like the Baltic Sea it will drop from the current 1 per cent to 0.1 per cent by 2015. The shipping industry will also be pressured to cut its carbon emissions. Like already explained, using LNG as fuel allows to cut CO_2 emission by about 25 per cent, sulphur oxides by almost 100 per cent and nitrogen oxides by 85 per cent.

The other impulse to start using liquefied natural gas instead of oil is its lower price compared to crude oil. Natural gas prices fell 32 per cent last year, whereas crude oil rose 10 per cent. Natural Gas and LNG are sold by producers in large-scale contracts. Up until recently the price models for such contracts were coupled to the crude oil price. This is no longer the case. Currently oil costs about six times more than natural gas. Natural gas prices have decreased for a number of reasons, the main one being that there is still more natural gas supply than demand, therefore natural gas storage has increased and raised the pressure on the prices. /26/

2.2.5 LNG world price

The price of LNG is shown $/MMBtu (million British thermal unit). In the picture bellow is the landed price for LNG in June 2012. The landed price is not the end price for the customer, to the landed price also the logistics costs and transportation costs needs to be added. The price for LNG is most expensive in Japan, one reason for the higher price is the higher demand after the closing down of the nuclear reactors in 2011. /27/

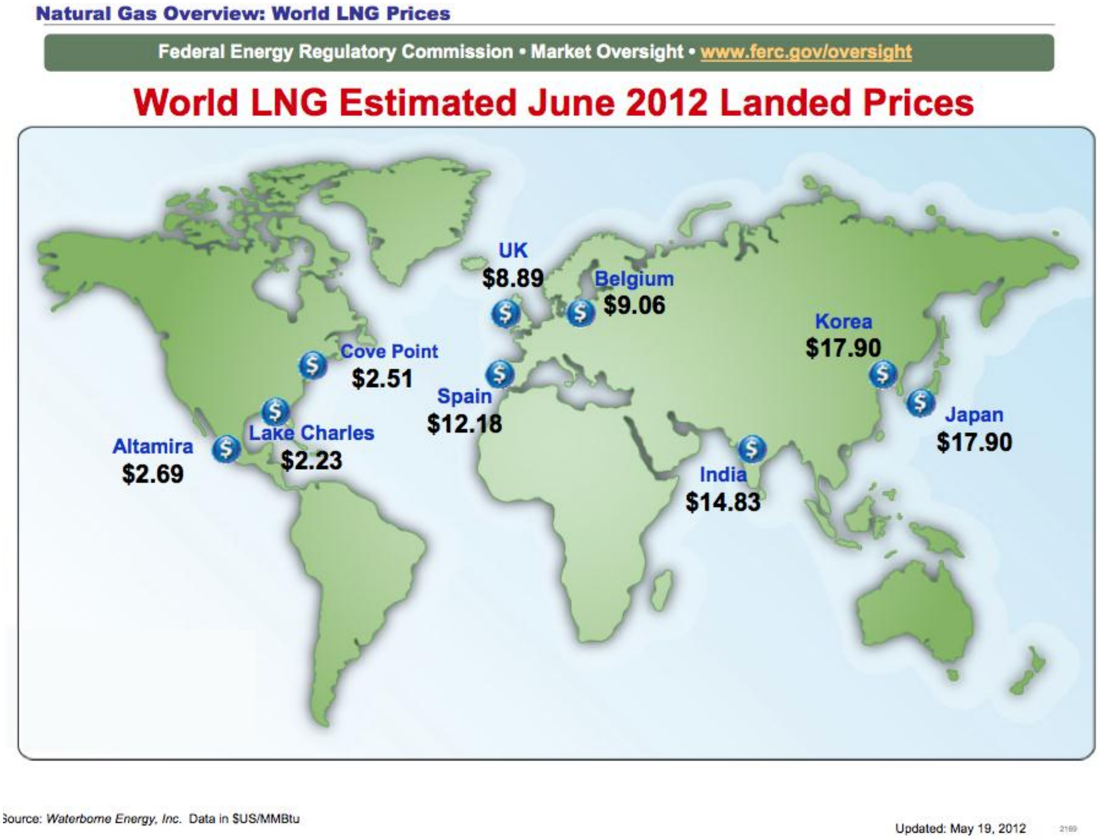

Figure 5, World LNG estimated landed prices

3 INLAND WATER SHIPPING

3.1 Fleet analysis

This chapter analyses the transport supply of inland shipping in Europe. At first, different criteria for discerning river ships are introduced. According to these, the current cargo fleet will be analysed under the following headings:

- Dry cargo fleet
- Tanker fleet
- Passenger fleet

3.1.1 CEMT classes

There are a standardised ship sizes established by the Economic Commission for Europe, (ECE) in 1992 and adopted by the European Conference of Ministers of Transport (CEMT) for classification of the European inland waterways /28/. Dimensions are given as length × breadth × draft. Different from seagoing ships, length is given as length overall, not length between perpendiculars. Length and breadth are fixed, depending on lock sizes and the geometry of the waterway (breadth, radius of curves). The maximum draft and the according payload varies according to the local water level, the figures for those are averages /29/.

Class	Length	Breadth	Draft	Description	Typical payload, Container Capacity
VII	285	34,20	2,50 - 4,50	3x3 Barges	
VI c	280	22,80	2,50 - 4,50	3x2 Barges	
VI c	195	34,20	2,50 - 4,50	2x3 Barges	16.500 t
VI b	195	22,80	2,50 - 4,50	2x2 Barges	11.000 t
VI a	110	22,80	2,50 - 4,50	2x1 Barges	6.000 t
V b	185	11,40	2,50 - 4,50	1x2 Barges	6.000 t, 400 TEU
	135	17	3,5	“Jowi-class”	5.300 t, 500 TEU
V a	110	11,40	2,50 - 4,50	Large Rhine vessel	2.750 t, 300 TEU
IV	85	9,50	2,50 - 3,00	Europa vessel	1.350 t
III	67-80	8,2	2,5	Gustav Koenigs	1.000 t
II	55	6,6	2,5	Campine	655 t
I	38,5	5,05	2,2	Spits/Peniche	359 t

Table 3, CEMT classes

Of these, the classes I to III are only of hereditary or regional importance. Following the principle Economy of scale, the bigger classes dominate the fleet.

The "Jowi-class" is not an official definition by the CEMT, but an established motor vessel class developed to optimise the use of type Vb waterways.

Further limitations on ship-size are bridge heights, which are especially important to the shipment of containers, determining how many containers can be stacked, e.g. carried on top of each other.

3.1.2 Hull configurations

There are different hull concepts for inland water vessels.

- Motor vessel: self-sufficient vessel, designed to travel alone
- Connected train (dt: Koppelverband): a motor vessel connected with one or more unpropelled barges, either in line or side to side.
- Push tow (dt: Schubverband): unpropelled barges connected to a dedicated push boat, that carries no cargo itself.

Pushing has replaced towing on account of better manoeuvrability, less manpower required and simpler barge construction. The Barges do not have to have steering and therefore also do not have to be manned individually. It was first developed in the United States and introduced on the Rhine in the 1960s.

Connected trains and push tows both offer the advantage of economy of scale when single ships are no longer practicable. Furthermore, there is the advantage of modularity: different cargos can be easily transported in different barges, and the number of barges can be varied to suit the current transportation need.

Since barges can be moored, loaded and also manoeuvred in harbour by small-dedicated harbour push boats, turnaround times can be significantly lowered. The push boat can start the next voyage with another set of barges independently of loading/unloading.

This is of course only partly true for connected trains. These are more commonly used as a permanent unit. Especially the configuration of one ship and one barge in line is popular to utilize the full lock length of locks that were designed to accommodate two ships.

3.1.3 Cargo carried

The most important distinguishing mark is the type of cargo that the ship is designed to carry.The most widely used distinction in the inland shipping business is the rather general threefold of dry cargo, tanker and passenger shipping /30/.

- The dry cargo-shipping segment incorporates all types of bulk cargo, which is the single most important commodity for inland shipping. But also break bulk, general cargo, heavy lift and rolling cargo are listed here.
- Tanker shipping is concerned with the transport of all liquid cargoes. The most important segments are mineral oils and chemical products. The transport of gases and powders plays a relatively small role.
- In the Passenger sector the main distinction is between vessels for day trips and cabin ships that are predominantly used for cruises. Public transport is very scarce; either not distinguishable from recreational day trips or done with ships classified as seagoing ships, e.g. Hamburg

3.1.4 Area of Operation

The table exemplarily lists a selection of transport volumes in 2010 as reported by the local departments of the German Waterways and Shipping Administration (WSV) /31/.

WSD West	Lower Rhine, befor Rhur	Olsoy - Border NL	174,793 Mio. t
	Lower Rhine, behind Cologne	Lülsdorf - Olsoy	161,056 Mio. t
	Rhine Herne Canal	Lock Duisburg Meiderich	14,973 Mio. t
WSD Mitte	Elbe-Seitenkanal	over all	7,480 Mio. t
	Mittellandkanal	over all	21,438 Mio. t
	Weser	over all	7,575 Mio. t
WSD Ost	Elbe	Lock Geesthacht	8,956 Mio. t

		Magdeburg	0,809 Mio. t
WSD Südwest	Middle Rhine	Bingen	61,074 Mio. t
	Upper Rhine	Lock Iffezheim	25,040 Mio. t
	Mosel	Lok Koblenz	14,267 Mio. t
WSD Süd	Main	over all	18,312 Mio. t
	Main Danube Canal	over all	6,206 Mio. t
	German Danube	over all	6,741 Mio. t

Table 4, exemplary German inland water traffic volumes from 2010

As is clearly visible, the Rhine is by far the dominant traffic axis. The governing body for this river system is the he Central Commission for Navigation on the Rhine, compromised of the bordering countries Germany, Belgium, France, The Netherlands, and Switzerland. Established in 1815, it is the world's oldest extant international organization /32/, which gives testimony to the highly developed network of stakeholders in place on the Rhine.

By contrast, the Danube and also the Elbe still suffer from the effects of the iron curtain and deficient infrastructure due to lacking investments caused by wanting economic power of the bordering countries. The Danube additionally suffered from the Yugoslav Wars, which for a long period severely disrupted all traffic and destroyed important infrastructures, mainly bridges and harbours. This caused a major relocation of cargo to road and rail, which shipping on Danube has not been able to win back. /33/.The total transport volume of Serbia in 2009 on the middle Danube has dropped 40% compared to 1990 /31/, to give just one example.

3.1.5 Age of the vessels

As with seagoing ships, the age of inland vessels is given according to the construction date of the steel hull. But compared to their average lifecycle of 25 to 30 years, inland ships have a much longer lifespan. For example, as seen in the next table, the average age of the German fleet in 2011 was 43,7 years.

The sudden drop in the early 1990s results from the addition of the comparably younger GDR fleet, namely the modern push tow fleet. The otherwise steadily rising average age can be explained with the low scraping activity. To a large extent, new buildings do not replace older vessels.

This development is representative of the whole European market, with the exception of the Netherlands and to some extent Belgium. The Dutch fleet is the main driver for innovations in the market and is steadily increasing its share. /31/

Since the hull structures are overbuilt to meet certain stability requirements and inland vessels operate predominantly in a freshwater environment, which causes much less corrosion, the steel structure has a very long lifespan, which often far exceeds the lifecycle of the equipment like propulsion, nautical equipment etc. It is therefore much more common for river ships than for seagoing ships to receive major overhauls with state of the art equipment. /34/

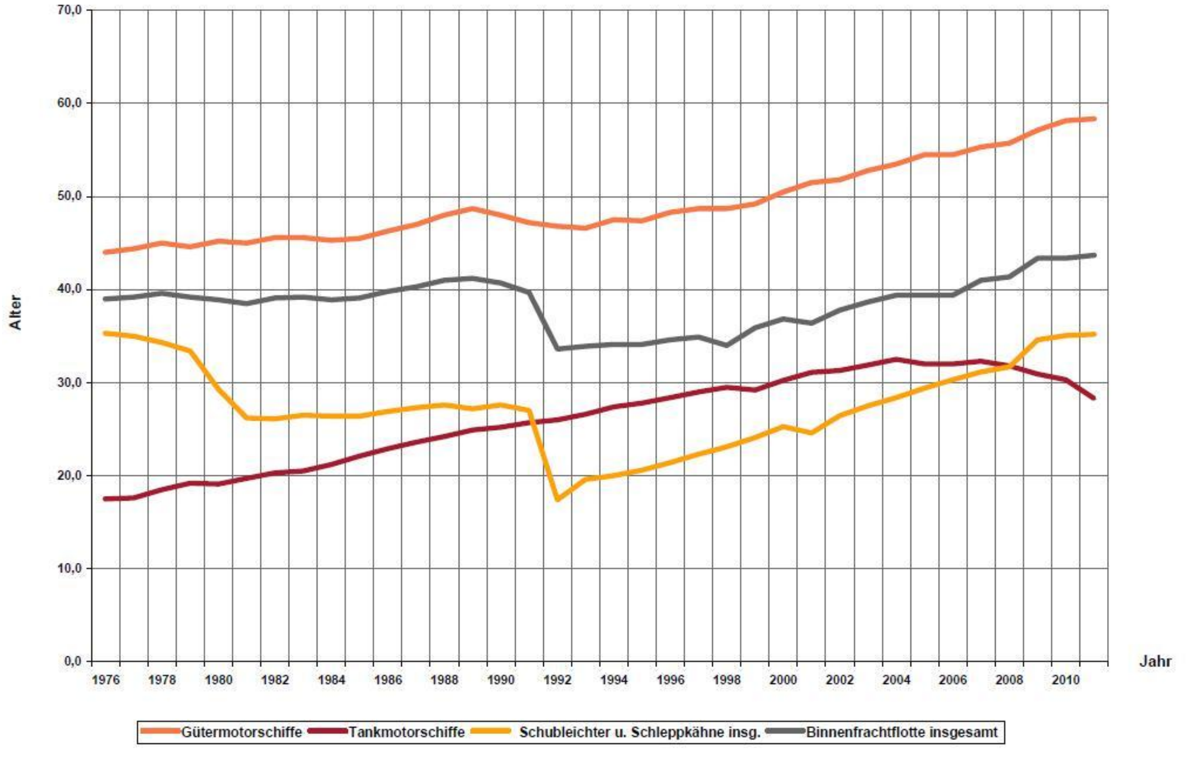

Figure 6, Average age of the German fleet by segments /35/

3.1.6 Dry cargo vessels

At the moment, Dry cargo vessels suffer from overcapacity mainly due to insufficient transport demand and hightened competition by road and rail. /30/ Especially the demand for imported raw materials like coal and ore has steadily declined due to the shift to post industrialization economies in Central Europe. /36/ As with the tanker fleet there is a shift to larger ship sizes, driven by mostly large newbuildings. To conclude however that smaller sizes will die out completely is a missinterpretation. On the less highly classified routes they are not in competition with large ships and will keep a small but steady share of the market. /37/ When the smaller vessel fleet is increasingly forced out of the mayor traffic routes, separating it from the large vessel fleet, newbuilding activity might start again in the smaller classes in the long term.
Potential for growth is scarce and depends on governmental support and requires a paradigm shift in cooperations to utililze the capability of inland water ships to carry containerized cargo and consumer goods. Those will be the main growth sectors for dry shipping, together with other marginal sectors such as rolling cargo, heavy lift cargo or recycling materials. Growth will however be marginal in terms of total cargo carried and the bulk cargo sector will continue the biggest market sector. /36/

3.1.7 Tankers

The tanker market continues to be in special periode of change because of a mayor shift in regulation. Single hull tankers are being phased out of the market until 2018, when all tankers need to have a double hull for safety reasons. The deadlines vary, for many chemical products it is the end of 2012, petrol fuels are due 2015 and diesel fuel, gas oil, light heating oil and kerosene – forming the biggest market segment - are the last ones to go in 2018. However, mayor shippers of these products have already annonced that they will use double hull ships exclusievly well before the deadline.
This has led to a spike in newbuilding activity of double hull ships in recent years wich is met by an increasing number of sales of old single hull ships abroad. The overall fleet size is has risen slightly and constantly, which has lead to an overcapacity just like in the dry cargo segment, but for other reasons. This overcapacity will disappear as the restructuring of the market continues./37/

3.1.8 Passenger vessels

The passenger market is very clearly divided into the day trip and the cruise segments.

The cruise segment has seen an almost constant growth over the last decade. An average of 10 new cruise vessels has entered the market each year from 2003 to 2010. The whole passenger market is less sensitive to economic fluctuations as the transport sector. Especially the cruise sector benefits from the demographic trends of societies growing older. For example in 2010 two thirds of cruise passengers in Germany were at least 58 years old. This target group was then expected to have grow by roughly 20 per cent over the next ten years. Cruise ships are expensive, with investment cost frequently 5 times higher than for freighters. They are typically owned by ship funds and operated all over Europe by large companies.

The daytrip market has seen much less unified development, with new building activity scarce and fluctuating. In Germany the overall capacity as decreased because of a big flagging out to maltese flag by one company on the Rhine. Disregarding that the capacity has stayed almost constant since 2003. Ships are mainly operated by small to medium sized companies and operate locally. /38/

3.2 Propulsion concepts

Propulsion is the means on how to move a ship through the water. Different propulsion systems are used on ships depending on ship type, target speed and service profile. /39/ The propeller can be regarded as one of the biggest energy consumers on the ship. Taking this into account, the propulsion system is always closely linked to the supply of power, which means in most cases electricity, to the rest of the ships systems for example control systems, light, pumps and navigation.

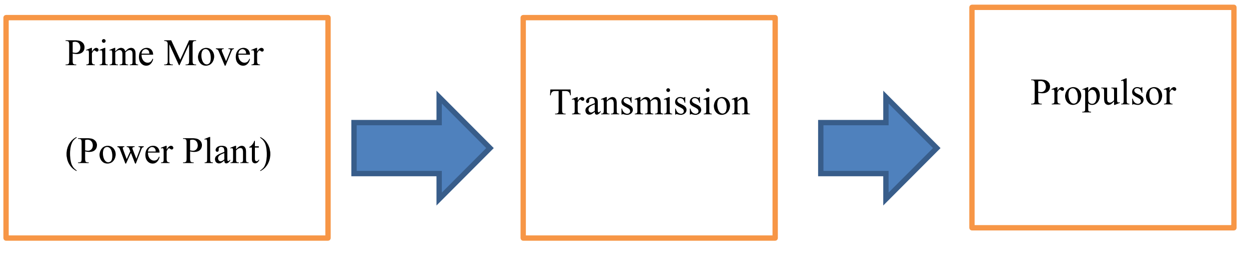

Figure 7, the main propulsion system components

The component putting mechanical energy into the propulsion system is the prime mover. In seagoing ships, the Prime mover is typically one of the following: /39/

- Diesel engine
- Gas turbine
- Steam turbine
- Electric motor

Of those, Diesel engines are by far the dominant form because of their high fuel efficiency. /40/ All other prime movers are limited to special cases. Gas turbines have a much higher power to weight ratio than diesel engines, which is why they are commonly used for fast and light ships like navy vessels or fast ships where the power demand is so high that it's a more economical solution than with a high-power 4-stroke diesel engine. /41/ Steam turbine systems have been used on LNG carriers to burn a mixture of marine gas oil and the boil of gas, with the steep price rises of both this is no longer economical. /42/

Inland water ships obviously do not fall into any of the special cases outlined above. This is why they are almost exclusively powered by 4-stroke diesel engines. 2-stroke engines are not an option because they are much too high to fit into any inland water ships and also too powerful. The power range of inland water ships is up to about 2500 kW. A typical small 2-stroke diesels, the Wärtsilä X35 has an output of 3475 kW and a height of 6,7 m. /43/ MS Otrate has a hull depth 3 m with the biggest inland water ships rarely exceeding 5 m.

Electric prime movers are always a part of a combined propulsion system, because the electricity powering the motor is always generated on board. They are covered under diesel electric propulsion.

3.2.1 Diesel mechanic propulsion

Diesel mechanic systems are the oldest and most established type of propulsion system. As outlined before, 4-stroke diesel engines are almost always the prime mover found on inland water vessels. By design, they have a much higher driving speed, typically between 300 and 850 rpm for medium speed and up to 1800 rpm for high-speed engines, than the operating speed of a typical propeller, which is up to 120 rpm. /44/ This is why all diesel mechanic systems on inland water ships are geared propulsion systems, where the gearbox reduces the speed to the operating range of the propeller. /45/

The main advantages of a diesel mechanic system are the low number of components and the low complexity of the system compared to other propulsion concepts and the high overall efficiency of the drive train, which is typically around 0,95. /45/

3.2.2 Diesel electric propulsion

The concept of electrical propulsion system is not new. The first ships with diesel electric propulsion were in operation as early as 1904 and the concept has obviously made a lot of progress since then. Since the 1980s, frequency controlled AC motors have replaced SCR, or thyristor, controlled DC motors as the dominant form of high power electric drives. This is due to the development of more sophisticated power electronics./46//47/

Figure 8 shows a typical diesel electric propulsion system in comparison with a diesel mechanic system.

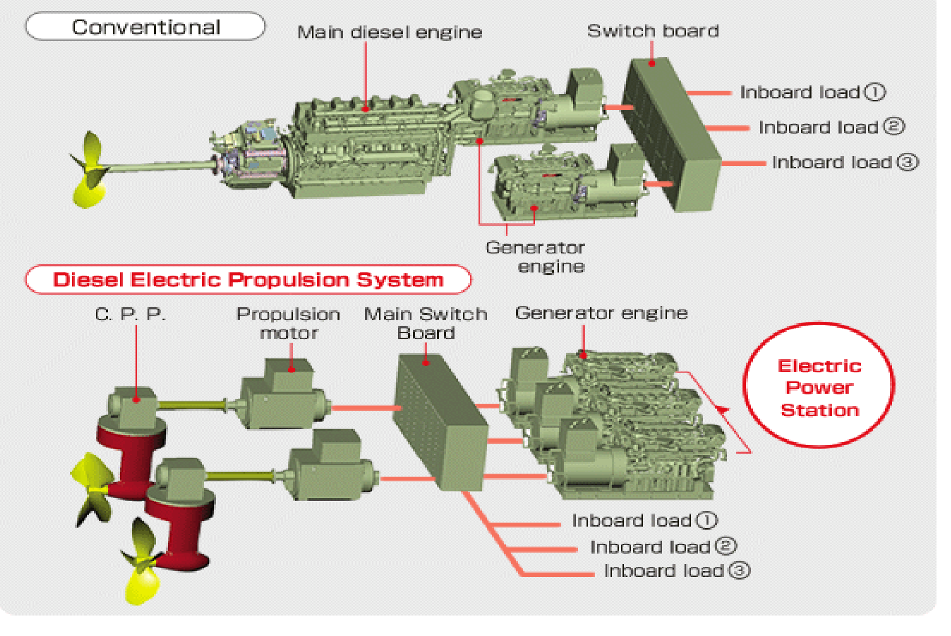

Figure 8, Comparison between diesel electric with diesel mechanic

The main advantages of a diesel electric propulsion concept are: /48//49//50/

- Integration: Both the propulsion and the electric grid of the ship are powered by a single power plant. This means that bigger engines can be used to generate electricity, which makes for a more efficient electricity generation.
- Free arrangement: Since the propeller is only mechanically connected to the electric motor, the power plant can be arranged anywhere on the ship. The required mechanical power can be split up into a smaller or bigger number of gensets, diesel engines connected to a generator, and placed anywhere on the ship. The placement of a diesel mechanic propulsion plant is much more limited by factors such as the shaft length.
- Modularity: the mechanical power is typically split up into a number of smaller engines. Because of this, diesel electric systems are able to operate more efficiently under varying loads. Diesel engines only operate at their best efficiency on a low rpm and power range. In a diesel electric configuration the load can be matched by operating a varying number of gensets at their optimal output range.
- Redundancy: Because of the modularity and flexibility of placement, a diesel electric system can be easily configured to provide a high degree of redundancy, like for example two separate power plants and two electric motors acting on two propellers that are all in separate rooms.
- Maneuverability: with the free arrangement and modularity of the propulsors a high degree of maneuverability can be achieved much easier and more cost effective than with a diesel mechanic system.
- Comfort: a number of smaller gensets can be arranged to cause a far lower level of vibration and noise than a comparatively bigger diesel mechanic plant. Certain types of electric propulsors like podded drives are virtually vibration-free.

The main disadvantages are:

- Complexity: a diesel electric propulsion system involves a number of complex electric and electronic systems that a diesel mechanic propulsion system lacks. A number of gensets utilizing high speed 4-stroke V engines, which have the highest efficiency and lowest space footprint in that power range are typically have a higher maintenance and spare part demand than bigger medium speed inline 4-stroke or 2-stroke diesels that are used in diesel mechanic propulsion.

- Less drive train efficiency: a diesel mechanic drive train has a typical efficiency of about 0,95. Since the mechanical power of the diesel engines is converted to electricity and then back to mechanical power in the electric motor, a diesel electric drive train has a lesser efficiency of about 0,9
- Higher cost: because of the higher complexity investment and maintenance cost are significantly higher.

To make the best use of this characteristic, a vessel must need to meet one or more of the following criteria in order to be a case for diesel electric propulsion:

- High electrical power demand with high degree of varying loads
- High degree of partial load for propulsion
- Space problems
- High comfort demands
- High demands towards redundancy
- High demands towards maneuverability

Big cruise liners meet all of these criteria, which is why they are most commonly utilizing diesel electric propulsion today. /48/ Other ship types are offshore supply vessels, icebreakers, war ships, and research vessels. /51//52/

For inland water ships a diesel electric propulsion system has historically not been regarded as an economic solution. With inland water cruise vessels there can be no discussion any more, they have the same demands as their seagoing counterparts. However with fuel prices rising steeply over the last decade, a number of criteria might now be considered under a different light also for cargo vessels:

- Space problems: Cargo capacity has been raised by increasing the hull size. However hull sizes have reached the operational limits like lock sizes, radius of river bends, with of fairways etc. on many routes. Increasing the cargo capacity can then only be achieved by utilizing the hull space more efficiently.

- Higher degree of partial load for propulsion: Inland water ships have a high degree of partial load because going downhill and driving in a canal are partial load cases, see chapter 4.1.3. Historically the potential fuel savings were not enough to cover the higher investment cost, it is our opinion that this has changed.

3.2.3 Propellers and Gearboxes

As outlined earlier, inland water ships almost exclusively use a gearbox. There are two types of gearboxes in use, depending on how the regulation of thrust and the reverse from forward to backward is realized. /53/ Today there are two common systems:

- Fixed pitch propeller (FPP) with a reverse reduction gearbox: To reverse, the propeller has to turn in the other direction. This is achieved by stopping the engine, bringing it to a halt, changing the gear and then starting the diesel engine again. There is no clutch as in a car drive train, because the forces that have to be transferred are too high. To adjust thrust, the rotation speed is adjusted. FPPs have fixed blades and a smaller diameter hub than CPPs, which is why they are more efficient at the optimum operation point. At any other speed, a CPP is more efficient.

- Controllable Pitched Propellers (CPP) with a reduction gearbox: The propeller always turns in one direction at one speed. Adjusting and reversing the thrust is achieved by changing the pitch of the blades, their angle towards the rotation of the propeller. This is done by hydraulically turning the blades, which makes for a bigger hub. This makes for much quicker reaction time because a thrust reversal does not require stopping and starting the engine, which makes for better maneuverability. CPPs are more complex, more expensive and only available up to around 40.000 kW. /54/

Ships with a high degree of full load, as are most seagoing ships are cases for a FPP. However ships with high demand towards maneuverability like container ships, ferries, special purpose vessels etc. Most commonly use FPPs if they don't require too much power. Ships that commonly use FPPS are tankers, bulk carriers and large container ships./55/

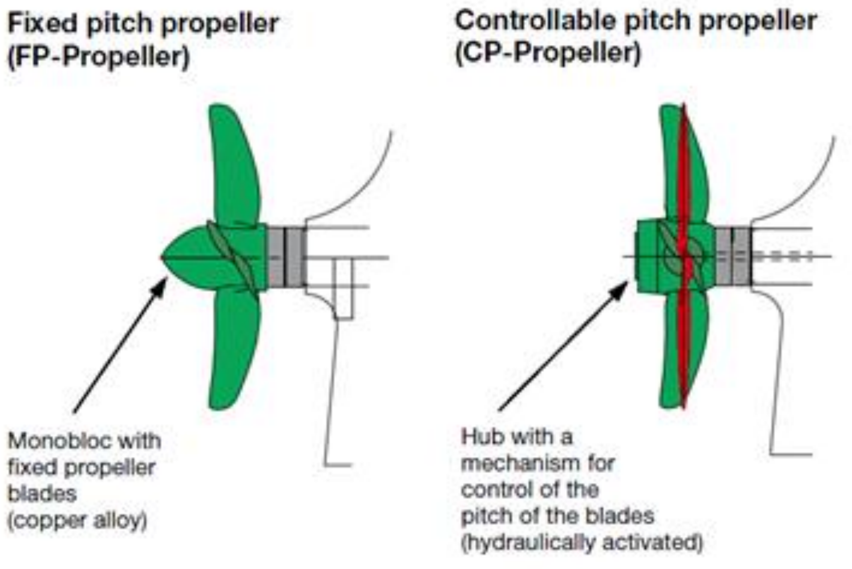

Figure 8, FPP and CPP propeller

Today new built inland water ships are commonly fitted with a CPP, because of their partial load characteristic and the high demand towards maneuverability. However older vessels, that make up the biggest part of the fleet are most commonly fixed with a FPP and a reverse reduction gear because CPPs were more expensive, therefore not cost efficient enough and the maneuverability of the then smaller ships was not a problem for CPP systems.

The oldest system that is not common today anymore but can still be found on a number of older vessels is a CPP with a reduction gear. Here, to reverse the thrust, the engine is reversed. This is done by stopping the engine, bringing it to a halt, reversing the camshaft and then starting the engine again. This system is the one employed on our project vessel, MS Otrate

4 CONVERSION CONCEPT

4.1 The project ship MS Otrate

MS Otrate is a typical smaller German inland water vessel. She was built in 1980s and is a Europaschiff, type IV according to the CEMT classification. As such she has a very typical layout for a dry cargo ship of this era, with some unique features. See also table 5 for the principle data, image 10 for a smaller version of the General Arrangement, which can be found in full in the appendix.

Class	Europaschiff, CEMT class IV	
Length over all	80 m	
Beam	9.5 m	
Depth moulded	3 m	
Air Draft	abt. 6 m	from bottom of keel
Cargo Volume	1350 m	before conversion
	1232 m	after conversion
Payload	1532 t	
Main engine	707 kW (960 hp)	KHD 528

Table 5, Principle data MS Otrate

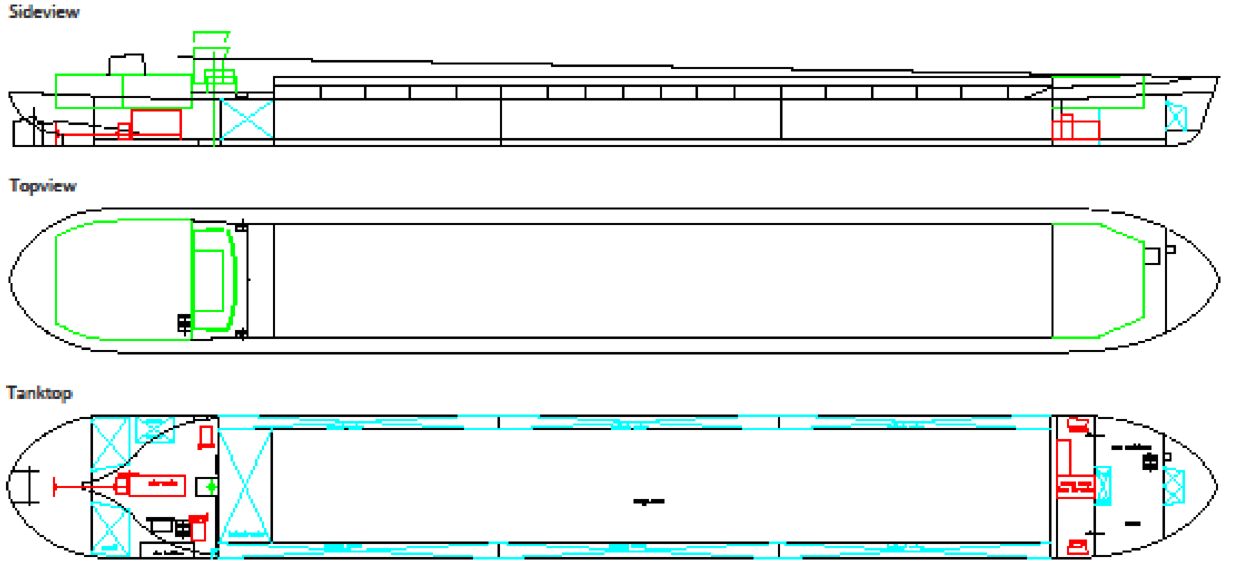

Figure 10, GA MS Otrate

4.1.1 Room layout

MS Otrate is divided into seven compartments. The frame spacing is 500 mm throughout the ship. The compartments are from forward aft: Forepeak, auxiliary engine room, bow thruster room (ex forward trim tank), cargo room with a double shell, aft trim tank, engine room, aft peak. Strictly speaking the auxiliary engine room and the bow thruster room are one compartment, as compartments are defined as rooms separated by a watertight partition, which is not the case here. But for better orientation they will be referred to as separate rooms.

Trim tanks are used to adjust the trim and to insure a minimum draft. They influence the maneuverability, the passing height to fit under bridges, the water flow to the propeller and other important operational criteria. Trim is defined as the difference between the draft forward and aft. When the trim is zero, the ship is said to be on even keel. Trim is the result of the weight distribution along the length axis. To regulate the trim, ballast water is adjusted said trim tanks

The original tank arrangement of MS Otrate has the ballast water kept in the two trim tanks listed in the compartment list and the double shell of the cargo room. This type of tank arrangement with tanks over the whole height of the hull is not in use anymore, because it sacrifices potential cargo room. In modern arrangements trim tanks are limited to the double hull, the double bottom and the fore and aft peak.

The two trim tanks are today no longer in use. One has been used to expand the auxiliary engine room and add a bow thruster for better maneuvering, the aft tank is a void space.

This peculiarity of MS Otrate, which is not uncommon in older ships, is helpful in a conversion to LNG because the void space is a logical place to arrange the LNG tanks.

The cargo room is 51.5 m (103 frames) long, 7.4 m wide, with a useable height of about 3.5 m on the sides and about 4 m in the middle, which a cargo room volume of about 1350 m . The payload is 1531t.

4.1.2 Propulsion end electricity generation

As outlined in Chapter 3.2 inland water ships are predominantly diesel-mechanic. MS Otrate is no exception. Typical for her size she is a single screw ship powered by one main engine, namely a Klöckner-Humboldt-Deutz (footnote: defunct, successor company Deutz AG sold its marine engine business to Wärtsilä in 2005) RBA 8 M 528 with a rated power of 707 kW (960 hp), a common engine in inland water ships built at that time. This medium speed 4-stroke diesel drives a single screw in a Kort nozzle via a reduction gear. Important to take away from this information is that in this configuration, in order to reverse the thrust the engine has to be stopped, reversed and then started again. This takes longer than the more modern alternative a reverse gear, where the engine can keep running in idle and the gear is shifted into reverse.

The bow thruster is a diesel-mechanic retrofit, located in the bow thruster room. It is driven by a 220 kW (300 PS) Scania.

Electricity was originally supplied by one genset located in the main engine room on starboard and a smaller generator driven by the main engine. Three generator sets of different type and age have been added over the years. Two are located in the bow thruster room close to the shell on starboard and portside. The fourth is located in the main engine room on portside. It is the only one incased in an insulating cover.

Noteworthy here is that inland water ships are only required to isolate the engine room against fire, not noise. Which genset is used to power the ship at night is therefore often decided according to noise. For example if the ship is tied up to another ship on starboard, a genset on portside will be used.

So in all, there are 6 diesel engines installed at present to cover all energy needs, all of different type and rating. From an operating point of view this is less than ideal, because it increases the costs for maintenance and certification significantly. This however is not uncommon in inland water ships, where the machinery changes over the long lifespan of the hull, as explained in outlined in chapter 3.1.

All engines run on the same fuel:, inland water ship diesel, a trading name for a light gas oil, see chapter 4.4 .The fuel is stored in two stand-alone tanks at the back end of the engine room on both sides, accommodating the inward sloping walls that form the ships stern.

4.1.3 Running modes and consumption

It is common practice in shipbuilding to predict and calculate the energy demand and the resulting fuel consumption according to predetermined modes of operation, called running modes. For seagoing ships these typically include: high sea travel, maneuvering, anchor and different harbor modes depending on cargo operations like loading reefer containers, pumping liquid cargo etc.

An electrical power balance has to be made covering each running mode and submitted to the classification society. A draft of this balance according to the building specification is the base for the-design of the ship and in conjunction with the consumption data for the main engine according to speed can be used to determine the fuel consumption.

The same model was used to assess the mechanical power delivered and the consumption of diesel of MS Otrate and predict and compare the same for LNG. According to common practice in the inland water shipping industry the following running modes have been distinguished: uphill („Bergfahrt“), downhill („Talfahrt“), canal („Kanalfahrt“) and harbor („Hafen“). The required propulsion power and the according diesel consumption for MS Otrate can be found in table 6. For the modes up- and downhill the numbers are input from the owner of MS Otrate. The numbers for canal are derived from those two data points.

Running mode	Days per annum	Mechanical power into gearbox	Diesel cons.
units	[d/a]	[kW]	[L/h]
uphill	73	590	169
canal	36	331	109
downhill	73	196	64
harbor	183	0	9

Table 6, Running profile MS Otrate

The consumption in harbor is dependent on the activity on board, how many electrical consumers are running. At the time of construction of MS Otrate, a electrical power balance was not a necessary document for class approval. This means that the owner had no detailed information for us about his consumers on board and how high his average or total electrical power consumption is. Since the project is still in an early stage, the assumption of 50 kW grid load, about the power provided by the smallest genset, is workable, though rather on the conservative side. In the next step after the initial approval of concept a electrical power balance has to be made for the conversion by collecting the electrical consumers and projecting their average time of operation in a quick survey on board.

Leg	Mech. power	distance	speed	time	diesel consumption / h	diesel cons. total
-	[kW]	[km]	[km/h]	[h]	[L/h]	[L]
Uphill	590	846	9,5	89	160	14.240
Downhill	331	846	14,5	58	55	3190
total	-	1692	-	147	-	17430

Table 7, typical roundtrip for MS Otrate

A typical roundtrip according to the owner can be seen in table 7.

With projected total LNG tank capacity of 31,7m³ one container needs to be exchanged after the uphill leg which consumes about 34 m³.

4.2 Technical Concept

The stated aim is to convert MS Otrate to gas-electric propulsion with sparkplug ignited pure gas engines. This gas-electric concept was chosen over a gas-mechanic solution before the start of the project based on the following points:

- Pure gas engines operating at fixed rpm powering a generator are a tested and established technology on land.
- Pure gas engines have problems with providing enough torque for quick manoeuvering in gas-mechanic configuration.
- Diesel-electric propulsion is a proven concept in shipping, though not widely used because most seagoing ships have high proportions of full load.

However it is well established that diesel-electric systems have advantages over diesel-mechanic systems in applications with high proportions of partial load. Inland water ships fit this description.

Based on these observations and previous work by our project partner Lindenau MIC we started to prepare a conversion concept in cooperation with two principle suppliers for the LNG components:

Scandiesel, a value-added reseller of diesel and gas engines providing the natural gas driven gensets and electric propulsion equipment

INOX India Ltd, a original equipment manufacturer supplying the LNG tanks and processing equipment

The frequently refered to general arrangement plan (GA plan) illustrating the conversion concept can be found in the appendix yy.

4.2.1 Gas-electric principle

The gas-electric propulsion, from the tank to the propeller, is presented in the following schematic, Figure 11

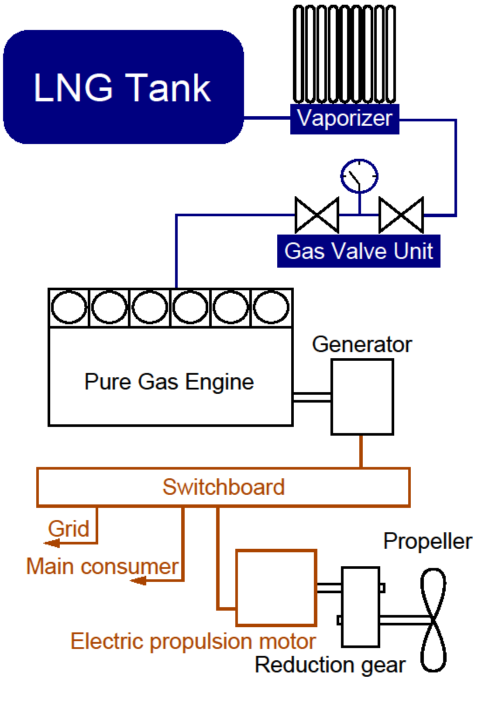

Figure 11, gas-electric principle

LNG is stored in a cylindrical, cryogenic tank below -162 °C. It is warmed electrically and brought into gaseous state in the vaporizer. The gas valve unit regulates the pressure of the natural gas to the specification of the engine. Here, the natural gas is burned in a proven technology, a spark plug ignited diesel engine working at a fixed rpm which powers a generator to produce electricity. The power is distributed by a switchboard into the grid to supply the household on board, to mayor consumers like the vaporizer and to the frequency controlled electric propulsion motor which drives the propeller via a reduction gear.

4.2.2 Gensets

The type and number of gensets is determined by the power required to match MS Otrates performance in going uphill. Based on the data for the uphill running mode from table 6, table 8 shows the calculation for the required mechanical power of the gas fueled gensets. Further assumptions are a grid load of 50 kW and in accordance with common shipbuilding practice a 15% reserve. The efficiencies are based on previous work on diesel-mechanic propulsion concepts. This gives a total required mechanical power to be installed of 843 kW.

step	[kW]	note	
Mechanic power into gearbox	590		
Electric power gensets propulsion	647	0,91 drivetrain efficiency	
Electric grid load	697	50 kW grid load	
Mechanical power gensets	733	0,95 generator efficiency	
Plus reserve	843	15% reserve	

Table 8, required mechanical power of the gensets

To achieve this, four gensets of 209 kW mechanical power each are projected, for a total installed power of 836 kW which gives a 14% reserve. Together with the conservative assumption for the electric grid load that is likely to decrease with a detailed electric power balance this will be sufficient.

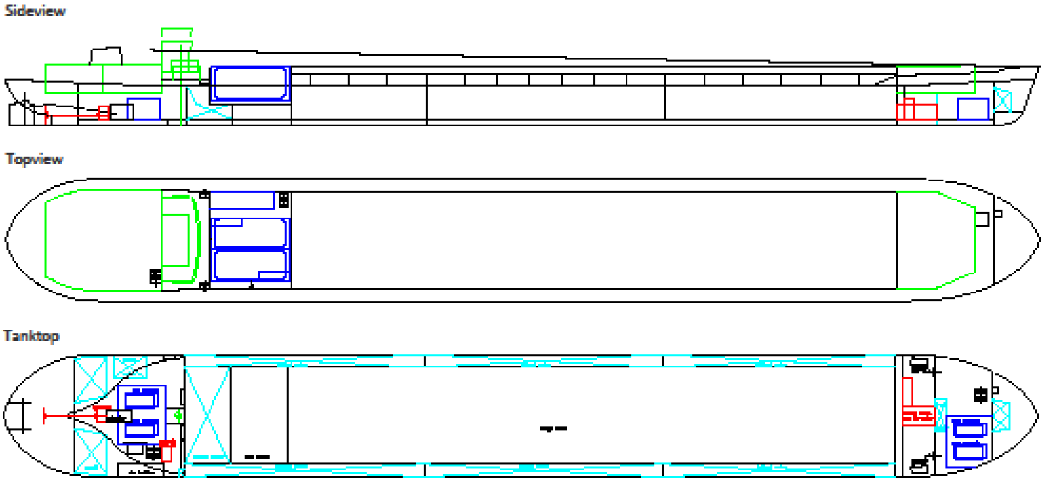

Figure 12, GA MS Otrate after conversion, LNG system in blue

The gensets will be supplied by Scandiesel in the typical form for marine application: engine and generator mounted shock absorbent on a common welded frame. They will be powered by a 4-stroke inline 6 TEDOM pure gas engine that is proven in land borne application. They are started electrically which avoids relying on a limited supply of compressed air, safe starting at all time will be provided by the battery grid already on board and one diesel gensets that will be kept on board as emergency engine.

The gensets will be arranged in two pairs, one in the main engine room in place of the old main engine, the other in the auxiliary engine room on starboard, see the GA plan and figure 12.

In the main engine room the gensets can be connected to the exhaust and cooling systems of the former main engine. In the auxiliary engine room these need to be added.

4.2.3 LNG Tanks

As will be explained in chapter 4.4.4, our conversion concept relies on containerized tanks to provide flexible fuel supply in a forming market. There are a number of criteria that govern the number and placement of the tank containers on board:

Passing height under bridges: MS Otrate is equipped with a lowerable wheelhouse. The container tank has to be placed so that the pacing height stays the same and that sight from the wheelhouse in lowest position is not impeded

- Safety: the tank containers will be placed on the open deck to ensure safety in case of a leak or emergency venting of LNG because the gas can freely evaporate without forming a flammable mixture.
- Access: the tank containers need to be easily accessible to a typical container gantry or mobile harbor crane, which also means that they are best stowed longitudinally
- Room for auxiliary equipment: sufficient space for the vaporizer and gas valve units and other equipment like a possible bunkering station must be available next to the tank containers

Only one solution ensures all these criteria with minimal loss of cargo volume. The containers will be stowed in a recess before the wheelhouse, utilizing the void space (ex trim tank), as can be seen in the GA plan. This results in a loss of 4.5m cargo room length, which is about 9%. As the cargo room cross section is constant, the percentile loss of cargo volume is the same. For an initial assessment of the commercial consequences see chapter xx

Other theoretically possible locations for the tanks were ruled out for the following reasons.

- On top of the accommodation: Passing height is severely impeded.
- Instead of accommodation: In case of MS Otrate, living space is not to be reduced. This would also not provide enough space.
- In the hold: would mean forced ventilation to ensure safety against flammable mixtures forming, more lost volume than the recess solution, an odd shaped cargo room which is undesirable because of inability to accommodate bulky cargo like heavy lift pieces and a not uniform hatch cover form.

The top of the tank containers will be in line with the hatch covers as to ensure visibility or passing height. This means that a deck has to be constructed at the height shown in the GA plan, as well as a new cargo room bulkhead.

If it proves necessary during a later phase of the project the tank containers could be placed lower on the double bottom itself, which would allow for example a car to be placed on board as is common practice on inland water ships and occasionally done on MS Otrate. Proper natural ventilation would need to be made sure off. The car, or other equipment, could be placed on a flat rack on top of one of the tank containers without impeding the sightline or passing height.

The minimum width for an access way required by the flag state is 600 mm (footnote BinSchUO §11.05), and since both container need to be accessed to connect them to the fuel system, the arrangement shown in the general arrangement plan was determined to be the best solution. Since Inland water ships travel on the right side of fairways and canals they typically go alongside on starboard. This is why the containers are placed on starboard, with the processing equipment on portside which makes it easier to protect against suspended loads.

Access into the recess is provided by a ladder on starboard to connect the starboard container and by a stairway to connect the portside container and access the processing equipment.

A free access way from one side of the ship to the other is provided in between the bridge and the tank recess.

The main properties of the tank container can be found in the container factsheet in appendix yy. With two containers this gives a fuel capacity of 31760 l, or 13636 kg at 90% capacity. The connection to the fixed pipes running to the processing equipment will be achieved by 1m flexible coupling. The connection box is located at one long side at the bottom, on the right hand side. The containers are standard 20ft shipping containers which can be handled, stacked and transported without restrictions other than those that apply to other containers with dangerous goods.

4.2.4 Processing Equipment

The LNG processing equipment changes the properties of the natural gas so that it can be burned in the engine. In the tank, is LNG, natural gas at -162°C, near atmospheric pressure. The engine receives it at 20 mbar gauge pressure and room temperature. This change results in 600 times the volume.

This is achieved by the vaporizer unit, where the LNG is heated electrically and the Gas valve unit which regulates the pressure in the fuel system. This equipment will be supplied by INOX India Ltd., mounted on a common steel frame to be installed in the same recess where the tank containers are stored.

The processing capacity calculation is based on the gas consumption of one Tedom engine at full output of 209 kW: 56,8 m³/h. This gives a maximum natural gas consumption of 229 m³/h for a required mechanical power of 843 kW.

4.2.5 **Control systems**

To ensure safe and efficient operation of the fuel system, electricity generation and the propulsion two new control and monitoring systems need to be integrated into the ship and the wheelhouse. Functionalities of these systems identified by the team are listed below.

For the fuel system these include:

- Monitoring of the fuel level and pressures in the tanks to keep track of the holding time of the containers.
- A planning tool to schedule and order the time and place of refueling stops.
- Fuel supply control to provide enough fuel for the current energy demand.
- Fuel supply safety system monitoring the pressures in the gas pipes and executing emergency shutdowns if necessary.
- Monitoring system for bunkering, i.e. refilling the tanks on the ship

For the propulsion and electricity generation system these include:

- Propulsion control to transfer the commands from the lever in the wheelhouse into commands for the fuel supply system, the genset control and the electric motor.
- control system for the gensets, starting and stopping the gensets automatically according to the propulsion control
- Grid control system

The system for the propulsion and electricity generation is no new technology. Systems to control the grid and the electric consumers on seagoing ships are in the same power range as the system required for MS Otrate. There are also already a number of diesel-mechanic inland water ships operating which basically have the same system requirements. The only new requirement is the handshake with the gas fuel control system.

A gas fuel control system however is relatively new technology. Since there are already a number of ships running on LNG in Scandinavia there are systems for seagoing ships available that can be adapted to inland water ships. Another option would be to start from a system for LNG tankers. A new requirement is the tool to integrate the schedule and places for refueling into the voyage planning. To assess the market situation and select a system for this and future conversions could be another a thesis or EPS project.

4.3 Regulations

There is no definitive standard for the use of LNG as fuel for ships as of yet.

The rules and guidelines that have been issued by different classification societies incorporate and refer to an interim IMO guideline for ships not covered under the liquefied gas carrier code **/56/** This chapter takes a closer look at guidelines for the use of gas as fuel for ships Source, footnote GL VI-3-1 guidelines for the use of gas as fuel for ships and the flag state regulation for inland water ships. /**57**/

4.3.1 Classification society - Germanischer Lloyd

All safety regulations are based on a single failure philosophy, any one mistake alone cannot result in an accident.

There are two design principles outlined for engine rooms in the guideline:

- Gas safe machinery spaces: Arrangements in machinery spaces are such that the spaces are considered gas safe under all conditions, normal as well as abnormal conditions, i.e. inherently gas safe.
- ESD-protected machinery spaces: Arrangements in machinery spaces are such that the spaces are considered non-hazardous under normal conditions, but under certain conditions may have the potential to become hazardous. In the event of abnormal conditions involving gas hazards, emergency shutdown (ESD) of non-safe equipment (ignition sources) and machinery is to be automatically executed while equipment or machinery in use or active during these conditions are to be of a certified safe type.

A simple consideration makes it obvious why a conversion is a logical case for a gas safe design approach: All engine rooms on a ship before a conversion are gas safe spaces. With a gas safe design approach all auxiliary equipment that does not need to be replaced for functional reasons can remain in the engine room. With an ESD-protected approach all equipment needs to either be replaced by gas safe equipment or be modified to shutdown automatically.

According to part 2.6 of the guidelines all gas piping need to be double walled. In case of a leakage the gas supply is to be automatically shut down. In order to avoid a blackout a multi engine installation like MS Otrate can be divided into two independent fuel supply systems, which is accounted for in our concept.

The shutdown of the gas is realized by a set of automatic valves called “double block and bleed valves”. The two shot-of valves have to be located in series in the gas supply line, at the beginning and the end with a bleed valve venting the gas line to the open air. In case of MS Otrate, each pair of engines will run on a separate fuel supply system.

At a point in the project there was doubt whether de definition „fuel supply system“ incorporates the vaporizer and gas valve unit. Consequence being that there need to be two vaporizer and gas valve units, each for a pair of gensets, instead of one vaporizer and gas valve unit for all gensets.

Both variations were requested from INOX India Ltd., both would be able to be realized in the space available in the tank container recess. After further study of the guideline we are convinced that only the part of the fuel supply from the which needs to be blocked and vented is necessary to be redundant, following the single failure philosophy. If during the consultations with the GL however this turns out not to be the case the alternative solution with two vaporizer units is ready to be implemented and still commercially viable.

4.3.2 Flagstate - Zentralstelle Schiffsuntersuchungskommission

The regulations by the flagstate are exclusively written with diesel fueled operation in mind and some specific rules basically make gas fueled propulsion impossible. For example all fuels must have a flash point above 55°C, the flash point of diesel, which was chosen to rule out gasoline with a flashpoint of 20°C, but also rules out methane with a flashpoint of -188°C. Another requirement are service openings to be able to clean and survey the fuel tanks, which is necessary and easy to realize for diesel tanks, but would be exceedingly difficult to realize for LNG tanks. All of these rules have been already identified during the planning of MTS Argonon, the first LNG fueled ship operational since beginning of 2012. They were temporarily waived by the flag state authority on the grounds of § 2.19 BinSchUO which incorporates the common practice that alternative solutions deviating from regulations can be allowed on the grounds of equal or better safety being proven.

More challenging will be to realize the required maneuvering properties that have to be proven in a sea trial after the conversion according to chapter 5 BinSchUO. The ship has to perform:

- A speed test and prove a minimum speed of 13 km/h through the water.
- Passing and collision avoidance manoeuvers.
- A crash stop, manoeuver going downhill.
- A turning maneuver if the vessel is below 86 m, which is the case with MS Otrate.

All these maneuvers have to be performed “rechtzeitig“, meaning in good time according to the letter of the regulation. No further indication towards required stop times or turning circles is given.

Of these maneuvers, the crash stop is the most critical, because it has the highest demands on the propulsion system. The crucial time is the one it takes to go from ahead to full astern. For this MS Otrate currently takes between 8 to 10 seconds. The diesel engine has to be stopped, come to a stand still, is reversed and then started again turning in the opposite direction when the torque acting on the propeller from the water still streaming past it is low enough so that the engine can start without damage.

With the gas electric propulsion the process is different. When the ship is running downhill it is only under partial load. Therefore not all gensets are running, in the worst case only one. To perform the maneuver, the electric motor has to perform the same stop and reverse as the current diesel engine. Since it does not need to be mechanically reversed and one of the prime characteristics of electric motors is near full torque at zero rpm, the critical process is to be found somewhere else. In the same time it took the diesel engine to reverse and start again and produce the full torque required by the propeller, the gas fueled gensets have to be started, connected to the grid and take the load of the electric motor. To assess whether this can be achieved with the proposed components and finally program the engine control systems to perform this manoeuver safely under all circumstances will be one of the big challenges after an approval of concept is achieved.

Apart from more data as to the performance of MS Otrate during these maneuvers, either from a previous sea trial or a trial to be conducted to specifically gather this benchmarks, the open water characteristics of the propeller are essential to calculate the torque the gas electric propulsion has to provide. These we have already requested from the company that maintains the propeller of MS Otrate. The next step is a combination of hydrodynamics and mechanical engineering: to calculate the forces acting on the propeller in a crash stop and project the required performance of the propulsion system.

4.4 Commercial

MS Otrate is of the ship type "Johann-Welker" this means she can trade on all German waterways, but is not big enough to compete on the Rhine under normal circumstances. The business model is built up of several family owned ships that work together in a collective this is called "Particulier".

All engines are run on the same fuel, a type of gas oil typically referred to as "Binnenschiffsdiesel", which translates to inland water ship diesel. There is no specific standard for this trading name, however it is the same as heating oil extra light (HEL) according to DIN 51603-Inland river ship diesel is energy tax-free. /58/

Natural gas, and therefore LNG, is taxed, but the taxes can be returned to the operator if applied for. A change of the energy tax law to make LNG as shipping fuel tax-free is currently evaluated. /59/

When calculation the return of investment, ROI we need to take into account the initial investment costs and the running costs for a specific period. In the river ship industry the time for an investment to get profitable is five years.

For the mechanical parts the supplier is Scandiesel, which has its headquarters in Bremen, Germany. Scandiesel works together with a number of standard engine manufacturers to provide complete propulsion solutions for marine and land borne applications. /60/

The LNG tanks system is provided by INOX India. INOX India Ltd. is a company based in India and offers comprehensive solutions in cryogenic storage, vaporization and distribution engineering. /61/

4.4.1 Investment costs

For MS Otrate the initial investment costs are listed in the following table:

Mechanical part	€
Gas generators set (x4) 240 kVA	340 000
Gas piping (x2)	15 000
Comissioning	15 000
Total	370 000

Electrical part	€
Engine controls	40 000
Switch boards	55 000
Bridge controls	10 000
Frequency converter	75 000
Electric motor	105 000
Comissioning	10 000
Total	295 000

Tank system	€
Crane rental (101h/year) (1year)	3030
Tank rental (yearly)	0
Regasification & contol skid (x2)	191250
Total	194280

Transportation (INOX)	1000
Incurance (INOX)	1000

Engine room preparation	20100
Optional supervisor (INOX)	1500

Total amount	859 280

Table 9, initial investment cost for LNG conversion

Most of the prices are according to real offers. There is no offer for the engine room preparations and the yearly tank rentals.

The engine room preparation calculation is only a rough projection. We have developed a excel sheet for making the calculation if the project gets a green light.

The yearly tank rental is integrated in the running costs calculation for MS Otrate. As seen on the initial investment cost table the total investment would be 859280 €, for converting MS Otrate from diesel propulsion to LNG propulsion.

4.4.2 Running costs

When comparing LNG and diesel running costs we have used the landed LNG price for June 2012. To get the customers price for LNG we have added logistics and transportation costs. The landed LNG price in Belgium 2012 is estimated to be 9,06 $/ MMBtu to get the end customers price we have added logistics costs 3,5 $/ MMBtu and for the transportation 1 $/ MMBtu.

When calculating the Diesel price we have used Bonapart Bunker Index for inland water shipping

In our calculation we used a period of five years, and an interest rate of five present. This gave us the following calculation for the net present value seen in table 10.

NPV= Present value of fuels savings	(1 655 813)	EUR			
Residual value =0	-	EUR			
Month interest rate = 5% / 12 months	0,00417	IRR			5%
Total months = 60	60		5	Years	
Fuel savings = Monthly supply of LNG * Dif.Fuel	31 247				

Table 10, Net present value for fuel savings

The fuel savings would be 1655813 € during a period of five years. We still have to add the costs for tank rental because MS Otrate is going to use a leasing contract for the tanks. If we use the same calculation as above and use the offered price for two LNG tanks, which is 192 000 €, we can assume that the company that is going to hire the tanks will take about 4000 €/ month. When we take away the LNG rental costs from the fuel savings we end up with savings worth 1443851 €.

With the conversion concept that is described in chapter 4 there will be a loss of cargo space with around 9 %. This has to be taken to account in further calculations. For the last two years Ms. Otrate has been running as an event ship. Before that it was running regular cargo. The loss of cargo space is not necessarily a problem. It all depends on what and how much cargo MS Otrate carries on a typical round-trip. Even in the case that it continues to do events there is the possibility that there is a profit to make from it from government funds for running a clean ship.

A key feature in our conversion concept is the use of containerized LNG tanks. As outlined in chapter 2.2, there is only a very scarce small-scale distribution network in place in Europe that will only increase based on demand. Stimulating demand however relies on reliable supply to insure unhindered operation of the vessels in Europe. To break this vicious circle, our solution is to use the well-established container logistic chain to supply LNG from a few distribution terminals on the northern European coastline to virtually any inland water port with a mobile crane or a container terminal.

4.4.3 Return on investment

According to our calculations the initial investment cost would be 859280 € and the fuel savings would be 1442851,00 € over five years. This means that the savings over five years would be around 584571 €. The earnings also depend on how the initial investment is handled. In the calculations we have made is so that the investment is paid without any interest on the investment. If this project goes further the initial investments pay off also has to be looked over.

Investment cost	859280,00
Fuel savings	1443851,00
Saving total over 5 years	584571,00

Table 11, Return of investment

On figure 13 we can see that the pay of time for MS Otrate would be around 2,5 years.

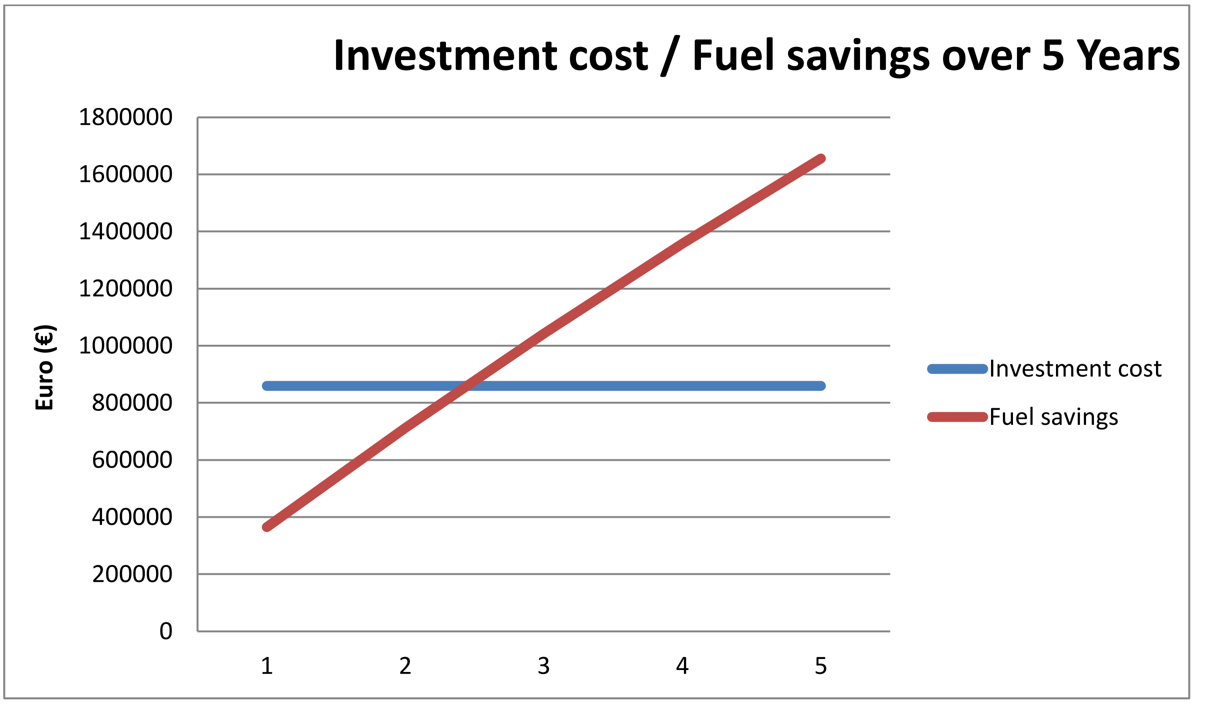

Figure 13, Investment cost / Fuel savings over 5 years

4.4.4 LNG Logistic

A key feature in our conversion concept is the use of containerized LNG tanks. As outlined in chapter 2.2, there is a very small-scale distribution network in place in Europe that only will increase if the demand increases. Stimulating demand however relies on reliable supply to insure unhindered operation of the vessels in Europe. To break this vicious circle, our solution is to use the well-established container logistic chain to supply LNG from a few distribution terminals on the northern European coastline to virtually any inland water port with a mobile crane or a container terminal.

For traffic on the highly frequented routes like the Rhine and close to the deep-sea ports where seagoing shipping will push LNG-development this is clearly a gap solution until a sufficient small scale LNG distribution chain is in place. But for smaller inland water ships also traveling on less frequented routes like the Elbe, parts of the canal network or the Danube fixed tanks will not provide enough flexibility for a long time and possibly

never will. The demand is to low and fluctuating to warrant distribution terminals.
The advantage of the containerized solution is that a bunkering station, once a standard has been established, can easily be integrated which allows ships to refill their tank containers on board just like a vessel with fixed tanks.

The proposed 20ft LNG container has a specified holding time of 131 days at full capacity. After this time the pressure inside has risen too high because of the slight but unavoidable warming of the cold liquid.
The scenario that a container exceeds its holding time and the gas has to be vented into the atmosphere to preserve the tank is highly unlikely in normal operation due to the following facts:

- Inland river ships are in harbor for typically about 180 days p.a. due to low water levels, waiting for cargo e.g. This time is spread out over a number of shorter periods in between voyages, 180 uninterrupted days of idling are unlikely.
- One typical round-trip as outlined in table 7 results in more than one container worth of consumption
- Even with half the assumed grid load (25 kW, which results in a natural gas consumption of about 7 m /h) a full container is empty after 57 days.
- In case of a foreseen longer period of cold layup (dead ship, no power consumption) or similar cases the containers can be arranged to be taken of and returned to the Container operator or given to another vessel.

4.5 Sustainability for MS Otrate

Human awareness about climate change is having its effects on governments and regulations. Toxic emissions have to be reduced from today's regulations step by step. This is also something that is under development in the inland water-shipping sector. This market is looking for different modes to reduce the emissions by analyzing the different types of fuel and propulsion systems. One solution is to start using LNG as new marine fuel to power the inland ships instead of diesel.

Compared to diesel, the CO_2 emission of LNG is reduced with 20 to 25%. The NO_x emission is lowered with between 85 and 90 % and the SO_x production is almost zero. The quantity of particulate bodies in the LNG emissions is close to zero.

4.5.1 Emissions

4.5.1.1 CO_2

LNG is mainly made up of methane. The combustion process of methane is shown below:

$$CH_4+2\cdot O_2 \longrightarrow CO_2+2H_2O$$

The exhaust for LNG consists mainly of Carbon dioxide and water.

It is possible to make a comparison for the CO_2 emission for the different fuels. The carbon content, carbon weight and the lower heating value for both fuels must be known. First of all, to estimate what the carbon content of LNG and diesel is, it has to be assumed that the chemical composition for diesel is for example $C_{12}H_{26}$ and CH_4 for LNG.

The carbon content is found by dividing the weight of carbon in the fuel by the total weight of the fuel, knowing that the atomic weight for carbon atom is 12 mol and 1 mol for hydrogen.

Carbon content for diesel: $$\frac{\boxed{12\cdot 12}}{\boxed{(12\cdot 12)+(26\cdot 1)}} = 0,85 \longrightarrow 85\%$$

Carbon content for LNG: $$\frac{\boxed{1\cdot 12}}{\boxed{(1\cdot 12)+(4\cdot 1)}} = 0,75 \longrightarrow 75\%$$

Knowing that the lower heating value for diesel is 42.7 MJ/Kg and 49.46 MJ/kg for LNG, we can estimate that 1.16 kg diesel equals 49.46 MJ. Therefore the amount of CO_2 emission can be calculated, and then it's easier to make a comparison between Diesel and LNG by using the following formula:

CO_2 emission for 1MJ= mass of fuel needed for 1MJ· fuel carbon content· 44/12. The calculation can be seen below:

Diesel: 1.16·0.85·44/12= 3.62 kg of CO_2

LNG: 1·0.75·44/12= 2.75 kg of CO_2

It means a reduction of 25% in the emission of CO_2. This value could not be as high as we calculate above due to the existing impurities in the fuel. Anyway, the reduction between 20 to 25 % is therefore realistic. /62/

4.5.1.2 NO_X

NO_X is formed by particles of nitrogen and oxygen. The reaction to form NO_x does not take place at room temperatures. It takes place when there is a high temperature for example in a combustion engine. /63/

LNG driven engines have lower emissions of NO_X than diesel driven engines. The lower emission for LNG is due to the lower combustion temperatures for the fuel. The reason for the lower NO_X emissions is the big amount of air needed to complete the combustion, this means LNG has a cleaner burning process. When using LNG as a fuel there is also less time for the NO_x particles to build up. /64/

According to Det Norske Veritas the NO_X is reduced between 85 and 90 %. /65/

4.5.1.3 SO_X

The amount of SO_X is related with the quantity of sulfur in the fuel. As the amount of sulfur in the LNG is roughly zero, almost no SO_x is created, in contrast with diesel where the amount of formed SO_X is significantly more. /66/

4.5.1.4 Particles

Particles are formed as a result of incomplete combustion. The amount of naphthalene's, benzenes and aliphatic are related to the purity of the fuel burned. Since LNG is cleaned during the liquefaction process, the emission of particulate matter is close to zero. /67/

4.5.2 Technical analysis of LNG engines

There are three different types of gas engines that can be used to run LNG inland water ships: lean burn gas engines, dual fuel engines and bi-fuel engines. The difference between these three engines is that the lean burn engines only operate with gas in contrast with dual fuel engines that run with a mixture of LNG and diesel. Bi- fuel engines can be powered with gas or diesel, but not with a mixture of both.

The maintenance costs for small engines using LNG as a fuel for inland water ships is harder to estimate, in comparison to diesel engines because we are talking about new technology. Not many of them have been manufactured and used for a long time in marine applications to know how they will work in the long run.

Comparing marine engines with the performance of the big LNG carriers that have been operating on the sea, these types of engines have been used for a long time and they have not yet had big problems. Although this might be seen as a good sign, this comparison is not conclusive because the engines that operate in the sea are larger and more powerful than engines that run inland water ships.

4.5.3 Impact on cost

The initial investment cost to build a LNG ship is higher than the cost to build a diesel fueled ship. This cost is around of 30% higher for lean burn gas engines. The reason why LNG engine is more expensive to construct is related with the higher price of the LNG installations. LNG technology is still under development and much engineering work is needed. The engineers often have to look for new and custom for the ships. This high cost will get lower when clear regulations will be established. Also the logistics for LNG fuel, engineers experience and suppliers of parts will be developed further. /68/

The cost of diesel is more expensive than for the same amount of LNG. The price for LNG will be even more attractive when it is used on larger scales. First it is necessary to build a LNG network supported by the governments. At the early scenarios of the transition period, there will not be many clients for LNG, which will make it unattractive for companies to invest in LNG, thus it will scare possible investors from powering their ships with LNG. That is the reason why governments are needed to gain new customers, given that they should support sailing on LNG for sustainability reasons.

The figure bellow shows the different costs that are involved in the transport and storage of LNG. These costs are based on the application of LNG powered barges in Norway. LNG price is directly related with the European gas price. The prices that are used in transportation and storage are:

- Small scale LNG production
- Freight to a bunkering port
- Terminal at bunkering port
- Bunkering operation for a terminal at bunkering port.

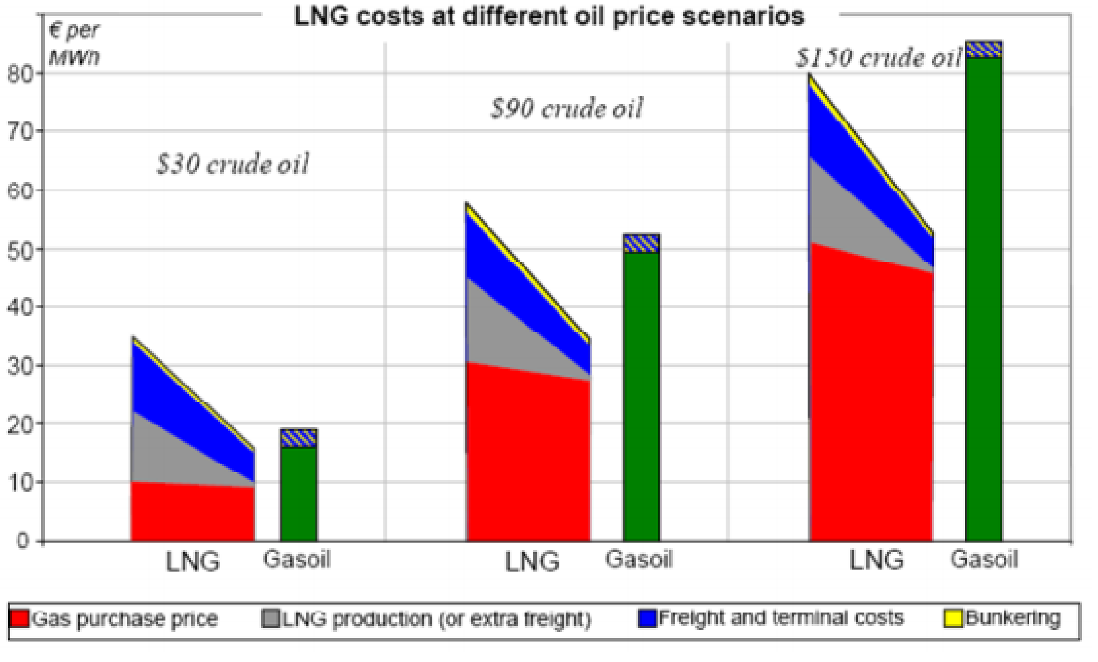

Figure 14, LNG prices involved in transportation and storage

To conclude, the main important factor for future use of LNG, is that a large scale logistics shain is built up to make it an attractive alternative. LNG will, on the long term, not only be cleaner, but also a cheaper alternative fuel.

4.5.4 Regulations

Nowadays, there are not defined regulations, for this reason is very difficult to attract new investors. After making a regulation regarding engines powered by LNG and LNG bunkers, ship companies can research opportunities into the LNG market. In the current scenario there are no regulations framed to use LNG in inland shipping.

5 SUMMARY

Based on what we know today, with a ROI of 2,5 years, the conversion of MS Otrate is a commercially and technically feasible project. However the data for consumer LNG prices are sketchy because it is a developing technology and the diesel price is becoming increasingly more unstable.

Another essential step is to find a container operator that is interested. This is necessary because the LNG network is being developed rapidly, but is still very scarce. Our aim is to drive the demand for an increasing LNG network, not be overtaken by a change in technology that seems to be inevitable.

5.1 The next steps

The next logical step is to present our technical concept to the regulatory bodies GL and ZSUK for an approval of concept and find out what we still need to work on. Commercially we have high hopes to secure consent for governmental support, in form of a loan from the KfW (Kreditanstalt für Wiederaufbau) or EU grants.

A solution with a dual fuel engine in diesel mechanic configuration has recently become an option again for LMIC with the opportunity to develop conversion kits together with Scandiesel for a range of diesel engines of a manufacturer of marine diesel engines they are about to add to their portfolio. A conversion with a dual fuel engine would rely on the same fuel system and can be assessed quickly based on a lot of the knowledge gathered in this report.

Before presenting the Owner Mr Rüffer with a concept and deciding whether to go further, a decision for gas-electric or dual fuel mechanic needs to be made.

Then comes a pursue a conceptual design with a shipyard or an engineering company in cooperation with the GL and the ZSUK and a final decision to convert MS Otrate. Other ships can be pursued as soon as that.

In case of a successful conversion there needs to be a monitoring to test whether the commercial and emission performance is as good as our projections. The development and possible easing of some of the safety requirements will also be resting on the performance of each running LNG inland water ship.

5.2 The ship types to target

The shipstypes in the market are listed below together with our interpretation of the suitability as a target for LNG propulsion. This is based on the fleet analysis and the lessons learned from developing the conversion concept for MS Otrate.

1. Tankers: highly suited
    a. Only newbuildings and conversions of excisting double hull tankers, since single hull tankers will be forced out of the market by latest 2018.
    b. They have to fulfill ignition safety standards on the whole ship, which eases the implementation of LNG safety a lot.
    c. They provide a lot of free deck space for LNG tanks on top of the cargo tanks which enables LNG tanks to be located on the ship without loss of cargo space.
2. Dry cargo vessels: suitability depends on individual situation
    a. Newbuildings and conversions depending on individual market expectation, loan strukture and savings of the owner.
    b. Push boats are a possibility because of their overall high power demand, though they have a pronounced space problem to fit tanks.
    c. Motor vessels depend on the individual possibilities to place the tanks.
3. Cruise vessels: very low suitability

    a. The high suitability of cruise liners for diesel-electric propulsion is the same for inland water ships as for seagoing ships. This makes them theoretically ideal ships for LNG propulsion.
    b. However the space demand of the LNG tanks is a KO-criterium. Any space above the tank top is reserved for hotel and cabins and a minimum of crew and auxilliar rooms.
4. Daytrip vessels: medium suitability
    a. Since they are operated locally they would only require small tank sizes if a dedicated local LNG terminal can be realized.
    b. As with dry cargo vessels, the fesability depends highly on the individual situation of the owner.

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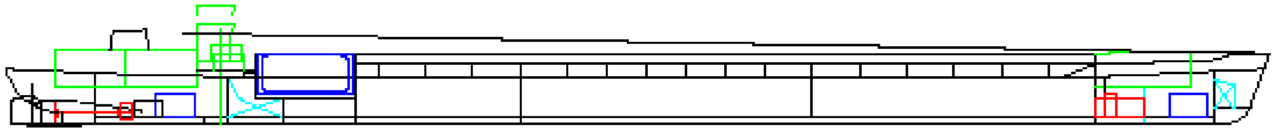
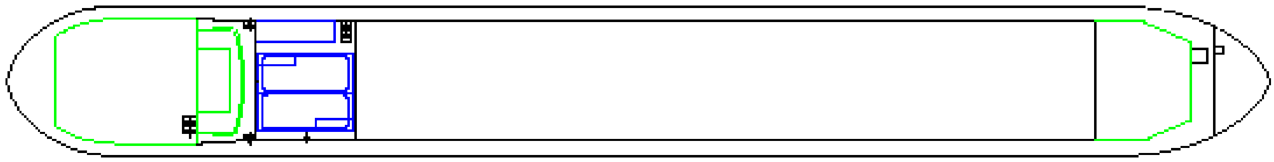
MS Otrate - Case study for a conversion to LNG fueld operation

Sideview



Topview



Tanktop

Owner + Operator

Helmut Rüffer, Binnenschifffahrt und mehr...

Type

Inland water vessel
Dry cargo

Class

Europaschiff	CEMT class IV

Dimensions

Length over all	80 m	
Beam	9.5 m	
Depth moulded	3 m	
Air draft	abt. 6 m	(Bottom of keel)

Cargo capacity

Length	47 m
Breadth	7.5 m
Height	min. 3.5 m
Volume	1232 cbm
Payload	1532 t

Gas-electric propulsion

Gensets	4 x 240 kVA
powered by	Tedom TG 210 G5V TW 86
Arranged in 2 seperate rooms	
pure gas, inline 6, 4-stroke	209 kW
Electric motor by Marelli	abt. 800 kW
frequency controlled	400 V

LNG fuel system

20ft tank containers	2 x 15.88 cbm (LNG)
can be exchanged or refilled on board	
Electric Vaporizer	

Commercial facts

Mileage	50800 km p.a.
Operational days	180 days p.a.
Diesel consumption	543000 l p.a.
LNG consumption	1351 cbm p.a.
	84 Containers p.a.
Fuel savings	365000 € first year
Return of investment	2.5 years

Disclaimer: All specifications and information have been compiled to best knowledge, but are early conceptual results, subject to changes and given without guarantee

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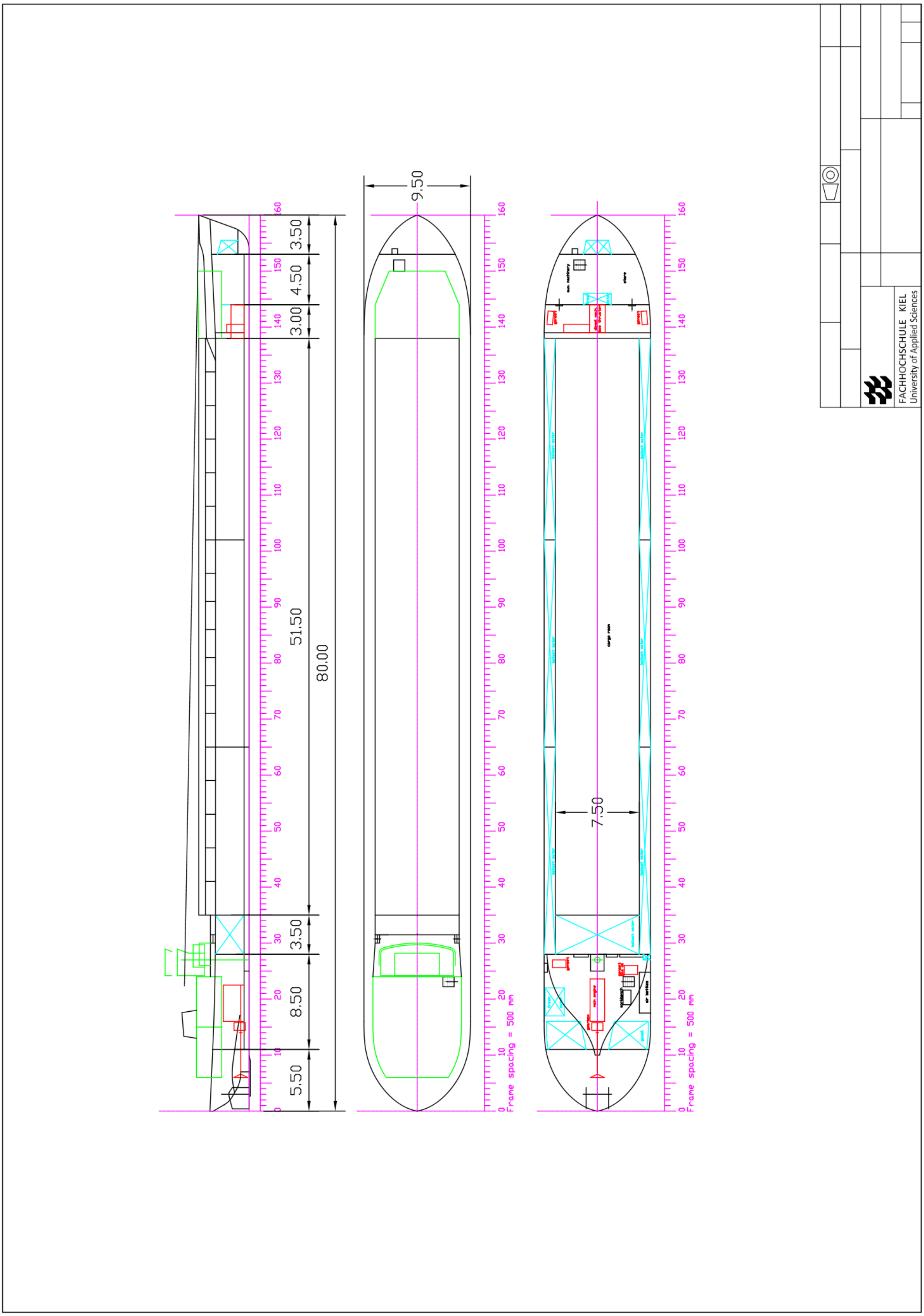
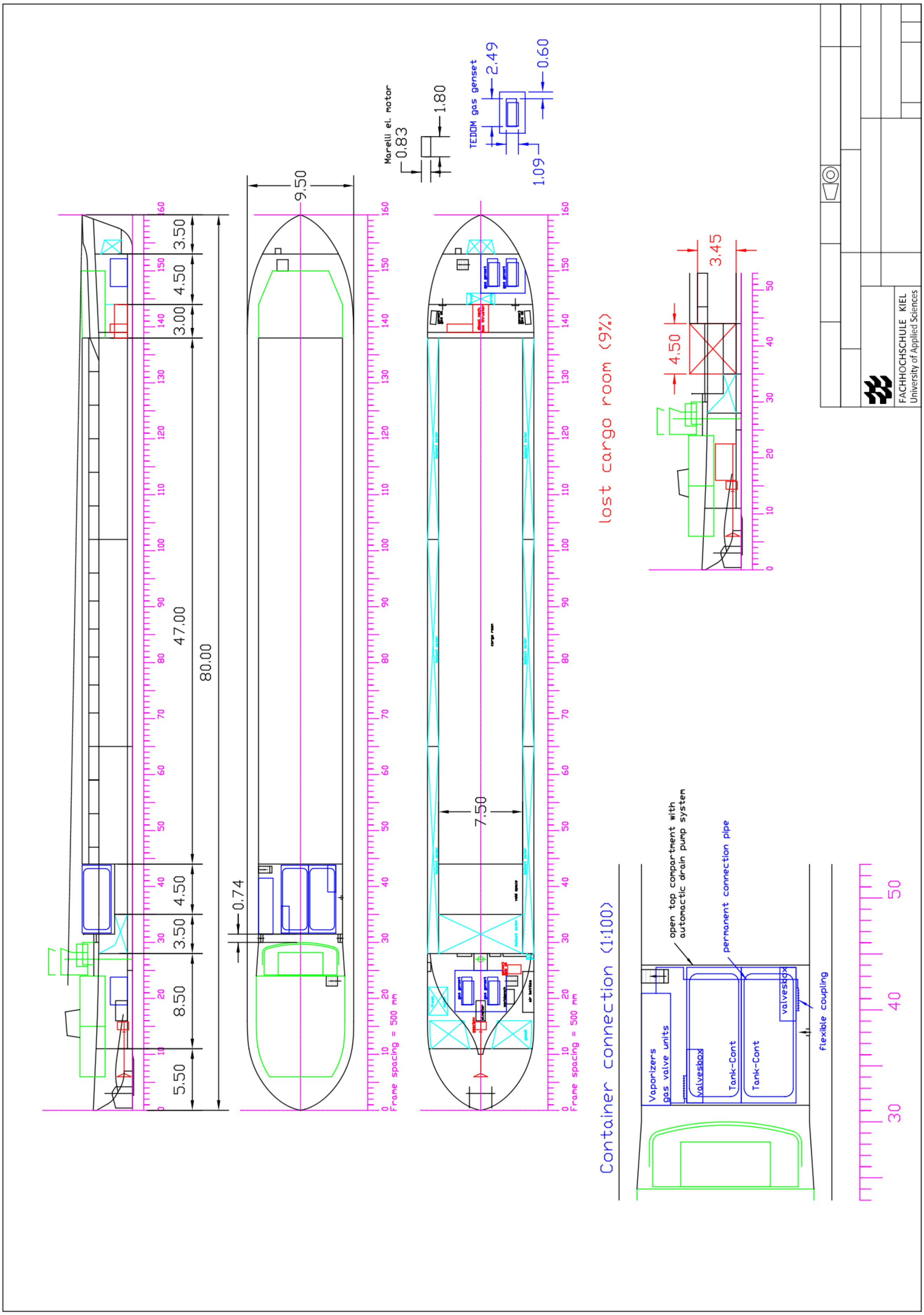
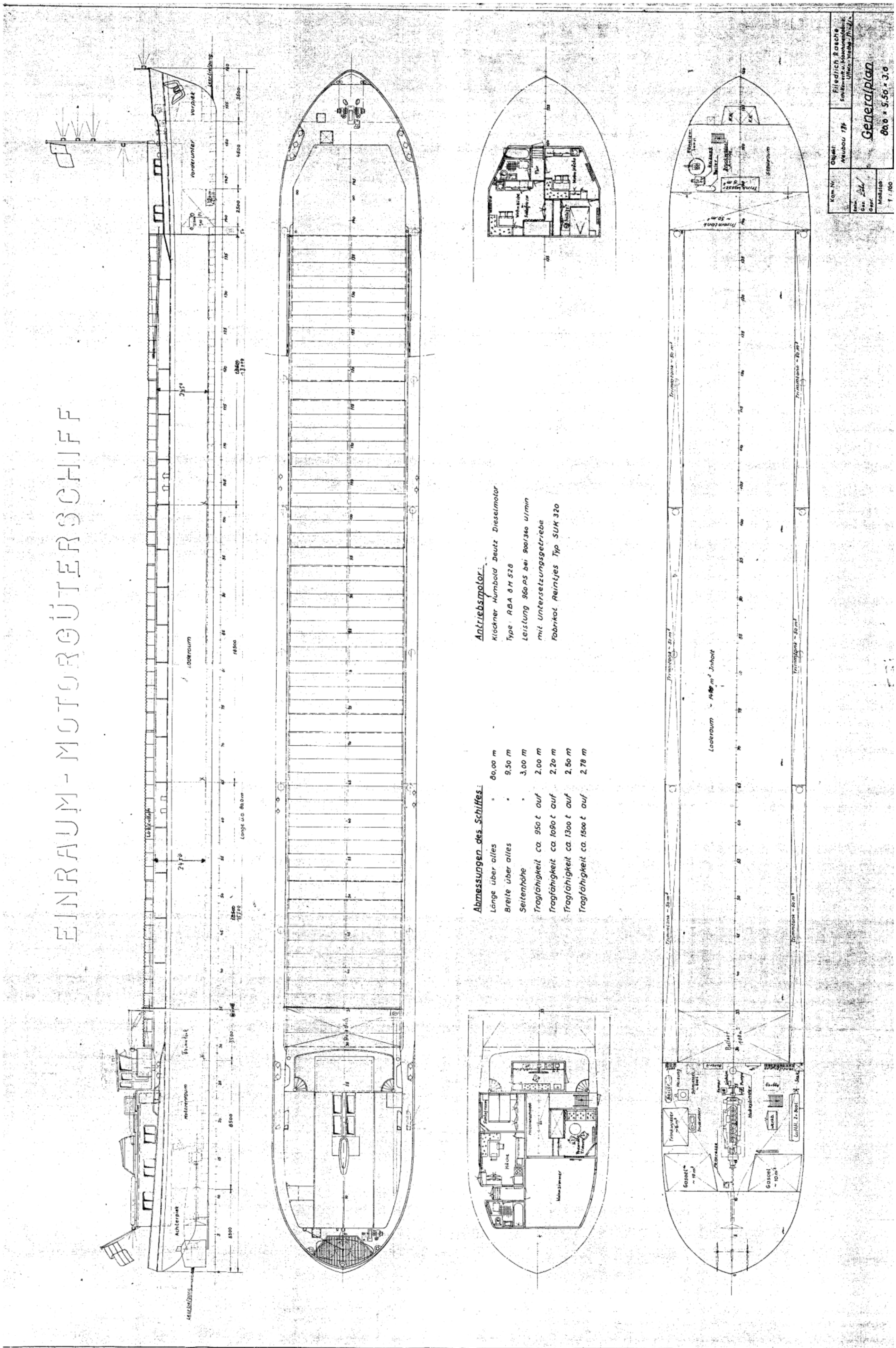
St-Nr. 1929841349
Ust-Nr. DE 271854856


9.50
3.50
4.50
3.00
51.50
80.00
3.50
8.50
5.50
7.50
Frame spacing = 500 mm
FACHHOCHSCHULE KIEL
University of Applied Sciences



lost cargo room (9%)
Container connection (1:100)
open top compartment with automactic drain pump system
permanent connection pipe
Vaporizers
gas valve units
valvesbox
Tank-Cont
Tank-Cont
valvesbox
flexible coupling
Marelli el. motor
TEDOM gas genset
Frame spacing = 500 mm
80.00
47.00
9.50
7.50
0.74
FACHHOCHSCHULE KIEL
University of Applied Sciences


EINRAUM-MOTORGÜTERSCHIFF
Abmessungen des Schiffes:
Länge über alles = 80,00 m
Breite über alles = 9,50 m
Seitenhöhe = 3,00 m
Tragfähigkeit ca. 950 t auf 2,00 m
Tragfähigkeit ca. 1090 t auf 2,20 m
Tragfähigkeit ca. 1300 t auf 2,50 m
Tragfähigkeit ca. 1500 t auf 2,78 m
Antriebsmotor:
Klöckner Humbold Deutz Dieselmotor
Type: RBA 8 M 528
Leistung 960 PS bei 900/360 U/min
mit Untersetzungsgetriebe
Fabrikat Reintjes Typ SUK 320
Friedrich Rasche
Schiffswerft u. Maschinenfabrik
Uffeln-Vlotho-Minden
Kom. Nr.
Objekt: Neubau 136
Generalplan
80,0 × 9,50 × 3,0
Entw.
Gez.
Gepr.
Maßstab 1 : 100