INNOVATE OR DIE
NATURAL GAS FUELLED VLCC
THE BALLAST-FREE SHIP

MANAGING RISK DNV

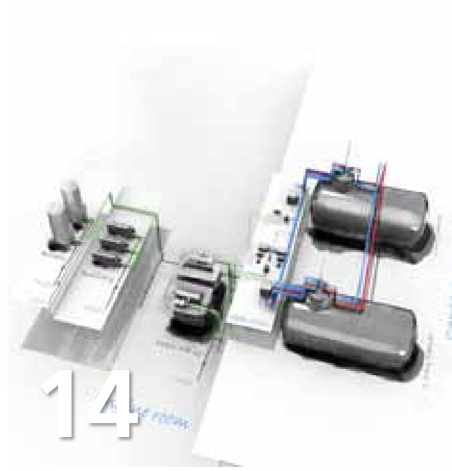
tanker update

NEWS FROM DNV TO THE TANKER INDUSTRY No **02** 2010

SPECIAL EDITION

TRIALITY

– TAKING ENVIRONMENTAL AND ECONOMICAL PERFORMANCE A **LONG** STEP FORWARD



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tanker update

WE WELCOME YOUR THOUGHTS!

Published by DNV Global Governance, Market Communications.

Editorial committee:
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Design and layout: Coor Design 1008-031
Print: Grøset, 7000/12-2010

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Online edition of tanker update:
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INTRODUCING TRIALITY VLCC

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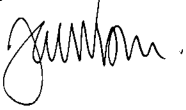


DNV's Triality innovation project has produced a VLCC that fulfils three main goals: it is environmentally superior to conventional VLCCs, has technically feasible solutions and is more economical than conventional VLCCs.

The introduction of inert gas systems (IGS), crude oil washing (COW), segregated ballast tanks (SBT), double hulls and Common Structural Rules (CSR) have all been important steps in the evolution of oil tankers over the last three to four decades. All of these improved safety and reduced oil pollution of the seas. The tanker industry can be proud of these achievements. Now the focus is shifting. Emissions to air are increasingly on the agenda of politicians, regulators, media and the public at large. The maritime industry can justifiably claim that shipping is the most environmentally friendly mode of transportation.

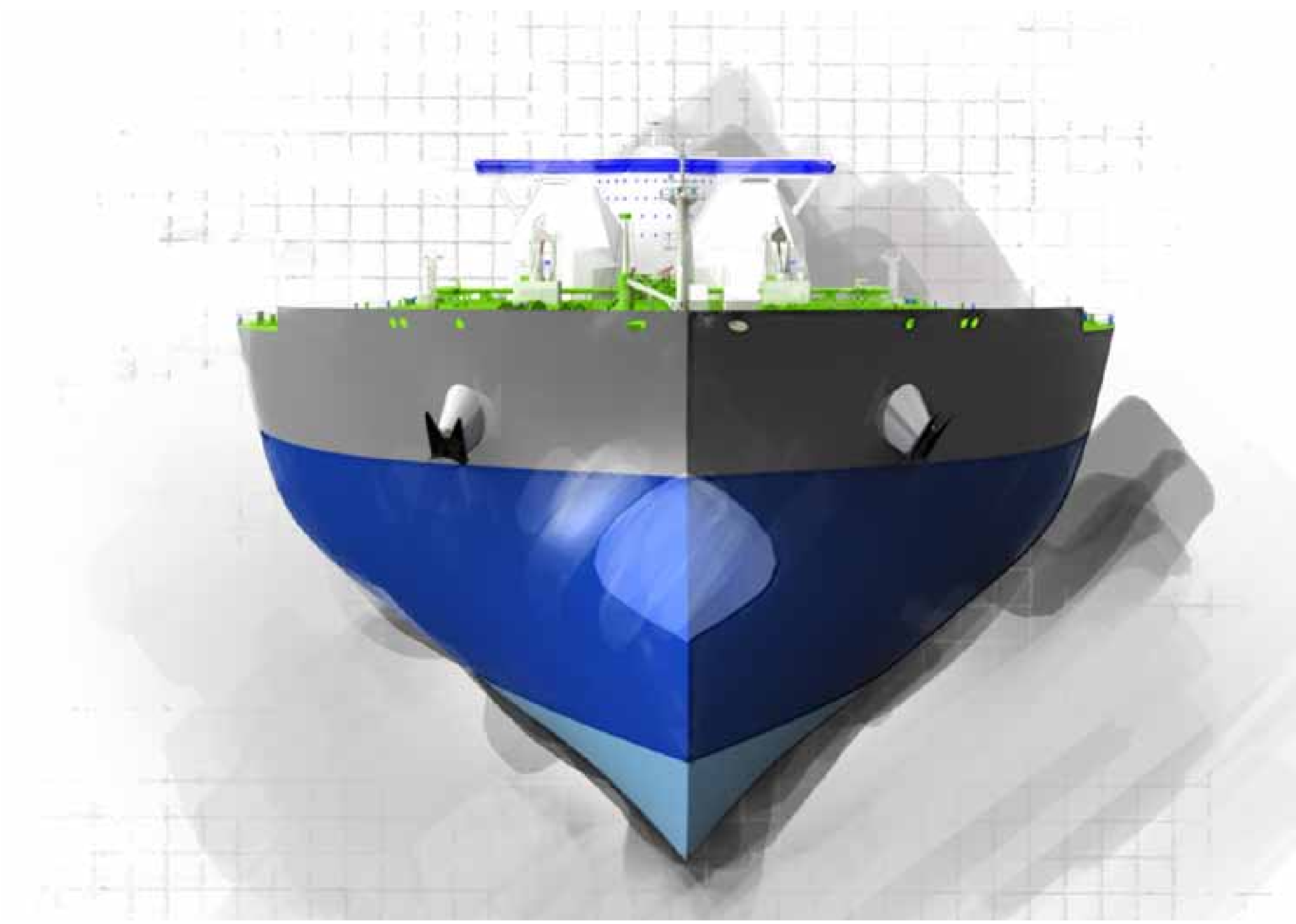
We have dedicated most of this issue of Tanker Update to the results of DNV's recent internal fast track innovation project - Triality. The challenge given to a strong team of more than 35 of our staff was to develop a new concept VLCC with the same cargo carrying capacity and operational range as today's ordinary VLCC. The new concept was to be characterised by the following main features: LNG fuelled, ballast-free and capable of effectively recovering Volatile Organic Compounds (VOCs), i.e. significant volumes of cargo vapours which would otherwise be lost to the atmosphere.

You may find the results of the project surprising and even exciting. The project was not intended to produce a detailed design or develop a complete specification. The aim was rather to identify possible solutions based on existing technology. The Triality VLCC will not be contracted in the very near future, but the project points in specific directions for the development of future designs. It is worth noting that features incorporated in the Triality concept may well be applied to smaller tankers too.

We expect Triality to receive a lot of attention. Some people will applaud it while sceptics will come forward with their objections. Sometimes cooperation is a key word for significant developments. Designers/yards, cargo owners/charterers, authorities and class societies all have important roles to play to meet the challenges we in the tanker industry will face in the years to come.

Our challenges may call for a bigger step this time…!

Enjoy the read.



Innovate or die

In 1954, DNV established its first research department with the sole objective of transforming itself from an imitator into an innovator in ship classification. The result was a shift away from empirical rules to a science-based rule set.

TEXT: **ELISABETH HARSTAD,** MANAGING DIRECTOR**,** DNV RESEARCH AND INNOVATION

Since then, DNV has continuously invested in research and development in order to remain an innovator in its business. Today, a wide variety of research and innovation activities are taking place in DNV, ranging from short-term development projects aiming for slight improvements in current standards, methods and tools to more long-term projects focusing on brand new opportunities in a changing world. Our longer term research projects are carried out by our strategic research unit and focus on new knowledge and services with a lengthier impact on DNV's business growth, while the shorter term projects are carried out in our operational units, ensuring close interaction with the market and operational needs.

The shipping industry's contribution to the reduction of greenhouse gas emissions is a hot topic. More energy efficient propulsion, new fuels, new hull forms and modified operating procedures are all part of the solution. Using advanced modelling technology, DNV is actively participating in a large number of projects, describing various pathways to low carbon shipping. Our COSMOS project, which is developing advanced simulation tools to optimise ship energy systems, is taking a new approach to holistic energy system design. Our new concepts for a container ship, Quantum, and tanker with LNG propulsion, Triality, are both examples of a holistic approach to ship design.

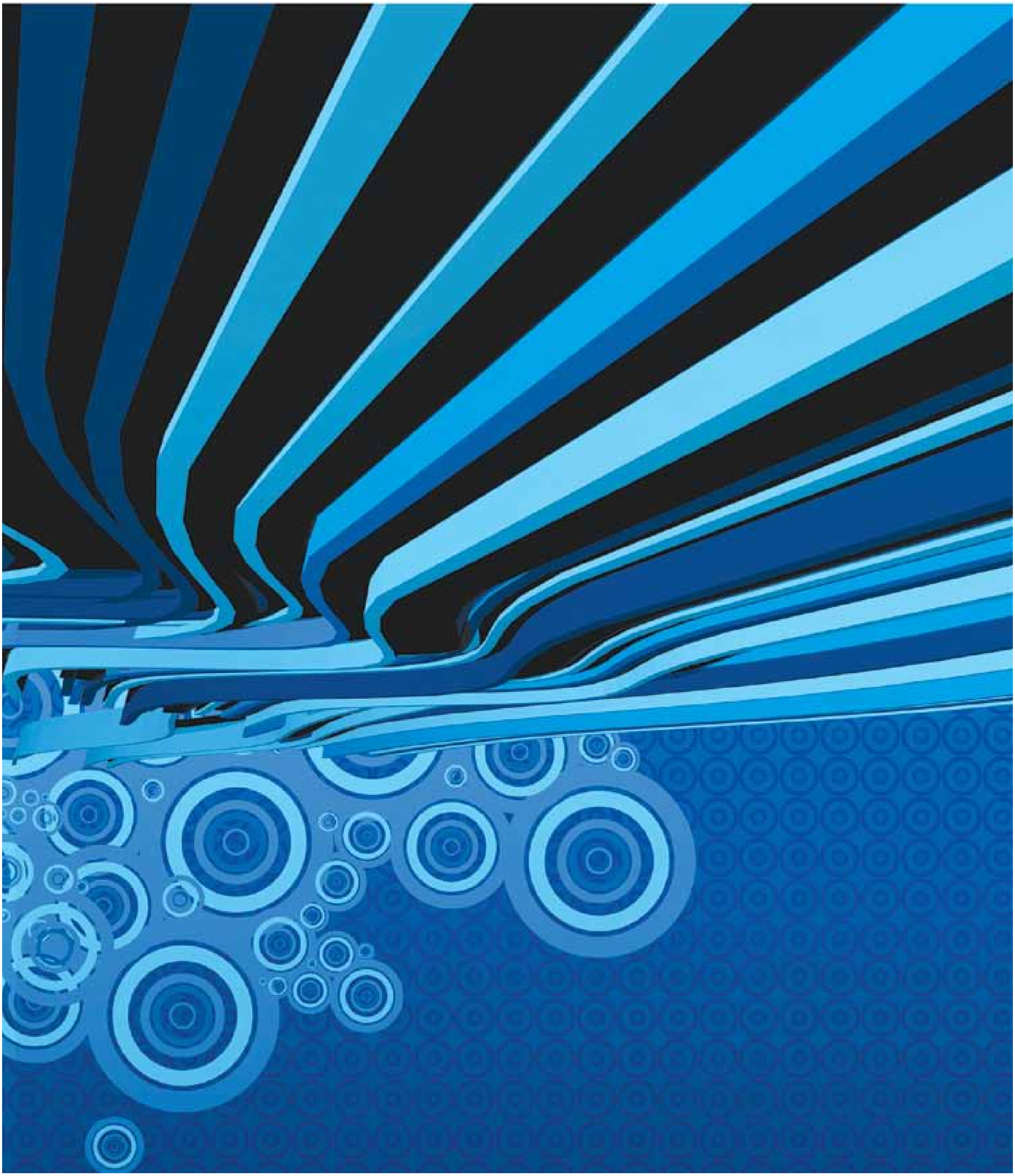
Future climate change will also affect the shipping industry in other ways and DNV is currently investigating possible extreme wave conditions through Extreme Seas, an EU-funded project for which we are the coordinator. Our position paper entitled Shipping across the Arctic Ocean describes possible scenarios as a result of less ice in Arctic waters.

Elisabeth Harstad

With the expected increased shipping and oil & gas activities in the Arctic, DNV has established a separate research programme focusing on Arctic issues, such as ice loads on floating structures and the effects of icing. Another DNV-coordinated project, Barents 2020 - Harmonising Industry Standards for Application in the Barents Sea, is an excellent example of successful cooperation between Norwegian and Russian experts in which Norway's experience of harsh environment operations in the North Sea is combined with extensive Russian experience of operations in Arctic conditions.

While keeping the environmental aspect high on the agenda, the safety and security aspects of shipping should not be forgotten. Navtronic, an EU-funded project, is investigating optimised weather routing, while Sectronic concentrates on the protection of ships and ports against security threats.

At regular intervals, DNV publishes Technology Outlook, in which we try to predict the future uptake of technologies in the industries we serve as a basis for launching new research programmes, acquiring new knowledge and developing new services. The future, however, seldom turns out as we predict. We believe that the future winners will be those that prepare for change and seize opportunities as they arise; the companies with a culture for innovation will not die!



DNV's Triality project:

Extraordinary innovation within a short time frame

What are the main challenges facing VLCC operations in the years to come? The conclusion arrived at was improved environmental performance. So when the project team took on the task of developing a VLCC concept of the future, a "green" ship design was given top priority. Could this also be done without increasing the complexity, and even remain financially attractive?

TEXT: **TORILL GRIMSTAD OSBERG,** TRIALITY PROJECT MANAGER, DNV

SHORT AND SWEET!

This exciting task was to be solved within a short and intense period of 8-9 weeks. DNV specialists from many different disciplines were involved. The project team included experts in naval architecture, hull strength, hydrodynamics, gas-fuelled ship systems, machinery, gas tankers, transport logistics, environmental issues and financial analysis. Close to 40 highly qualified DNV employees had been involved before the task was completed.

WHAT WAS THE GOAL?

Firstly, the goal of the project had to be clarified: to design a VLCC with a substantially smaller environmental footprint by reducing emissions of NOx, SOx, CO_2, particles and Volatile Organic Compounds (VOCs) from the cargo tanks and, if possible, doing something smart about the large volume of ballast water normally carried on the voyage to the loading terminal. The solutions were not to restrict the normal operation of the new VLCC compared to a conventional VLCC and had to be financially attractive. An important part of the project was to prepare financial and environmental calculations so that our concept could be compared with a conventional "base case" VLCC with the same cargo capacity and operational range.

NEEDS FIRST, THEN SOLUTIONS

A successful innovation project must map the needs first before looking for the best solutions. Initial workshops involving brainstorming sessions and clarification of the needs and scope were held in August/September.

The project group started off by mapping the typical VLCC of today and its operational patterns, and then brainstormed and gathered information about different ways of reducing the environmental footprint. Avoiding too complex solutions that would create extra work or barriers to operation was critical to the success of the project. The scope was soon narrowed down to the application of LNG as fuel, finding a good solution for reducing VOC emissions, trying to make a ballast-free hull, and looking at possible ways to reduce energy consumption. Due to the short project time, it was decided not to include all the available energy efficiency means and instead to limit the energy efficiency scope to that which could be gained as side effects from introducing LNG as fuel and a ballast-free hull.

Weekly project meetings were conducted to coordinate the different parts of the study. Since two of the participants were located in Singapore and two in Trondheim while the majority of team members were in Oslo, most of the project meetings were held as video conferences.

›› From left to right: Maria Karolina Olsson, Torill Grimstad Osberg, Tobias King, Ole Øivind Skaar, Christian Glørstad, Pål Einar Spilleth, Anders Tønnesen, Henrik Larsèn.
Not present when the picture was taken: Serge Schwalenstöcker, Håvard Nordtveit Austefjord, Sofia Fürstenberg (Singapore), Eirik Fernandez Cuesta (Trondheim), Ingar Bergh (Trondheim), Leng Yew Ming (Singapore).

THE STEERING COMMITTEE:

Jan Koren, Segment Director Tankers
Lars Petter Blikom, Segment Director LNG
Morten Lerø, Head of Section Tankers
Kang, Seog Tae, Senior Customer Service Manager, Korea

THE PROJECT TEAM AND OTHERS THAT CONTRIBUTED

The extended project team consisted of the following:

NAME	RESPONSIBILITY/RELEVANT COMPETENCE
Torill Grimstad Osberg	Project manager, gas fuelled ships, tanker cargo systems
Serge Schwalenstöcker	Ship design
Henrik Larsén	Financial analysis
Sofia Fürstenberg	Environmental assessments
Eirik Fernandez Cuesta	Routes, operational profiles, market FW as return cargo
Håvard Nordtveit Austefjord	Hydrodynamics
Pål Einar Spilleth	Gas tanks
Ingar Bergh	LNG market assessments
Tobias King	Ship design, ballast-free ship
Maria Karolina Olsson	Hull strength of oil tankers, VOC
Ole Øyvind Skaar	Financial assessments
Leng, Yew Ming	Market evaluations Asia, LNG pricing
Anders Tønnesen	Energy efficiency
Christian Glørstad	Hull strength of oil tankers, steel weight calculations

Other contributors were: Atle Ellefsen, Eivind Neumann-Larsen, Adam Larsson, Tormod Gjestland, Oddvar Deinboll, Eivind Ruth, Olav Tveit, Martin Davies, Gabriele Mazza, Odd Andersen, Arnt Egil Ræstad, Ingar Sarnes, Evangelos Boutsianis, Tormod Ravnanger Landet, Harald Bergsbak, Zang, Yuelong, Wang, Jian Zhong, Johan Vedeler, Christian Andersson, Cosmin Ciortan, Tom B. Hansen, Vidar Ådnegard and Arthur Iversen.

DNV's 3D modelling centre in Poland produced a 3D model of the ship. Innoco AS ran the initial workshop. Making Waves AS produced animations, pictures and presentation material. MAN Diesel & Turbo, Hamworthy Gas Systems, BW, Yarwil, Hamworthy Moss, Wartsila, OceanSaver, H + H, Couple System and other external parties provided useful information.

You can read about the project's results and conclusions in a number of articles in this issue of Tanker Update, and a separate brochure has also been published.

Setting the direction for the development of future crude oil carriers?

Last August, DNV started an internal fast track innovation project. The task was to develop a concept VLCC which was environmentally superior to and more economical than conventional VLCC designs, all based on technically feasible solutions.

TEXT: **TORILL GRIMSTAD OSBERG,** TRIALITY PROJECT MANAGER, DNV

Torill Grimstad Osberg

The Triality is an innovative concept VLCC that fulfils three main goals:

1. It is environmentally superior to conventional VLCCs
2. It has technically feasible solutions
3. It is economically better than conventional VLCCs

The name Triality refers to the three points above as these were the three main objectives of the DNV innovation project. Triality is defined as "three united, state of being three."

THE FOLLOWING SPECIAL FEATURES were identified,

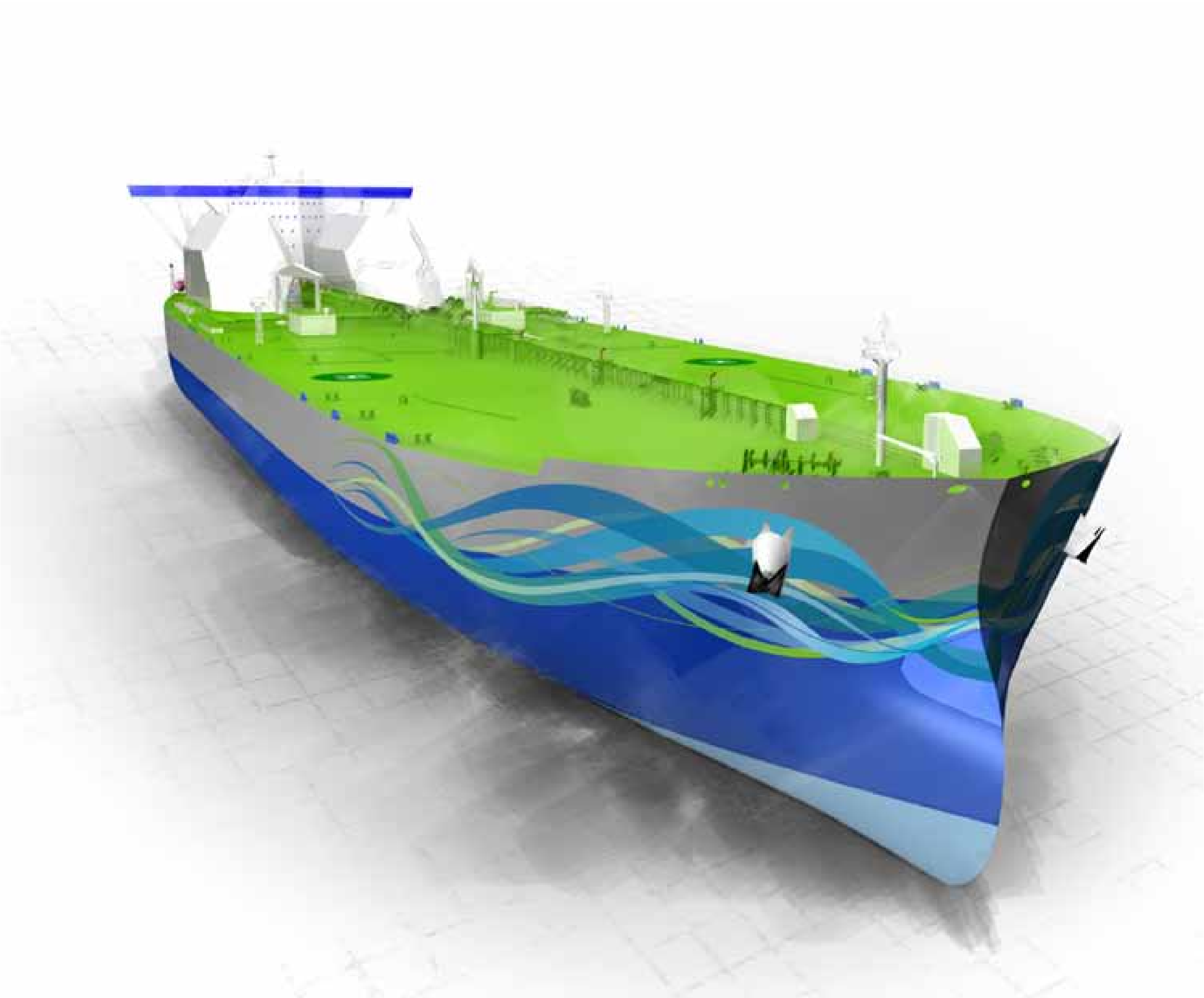
1) no need for water ballast as a consequence of the new hull design and new cargo tank divisions
2) LNG fuel for propulsion and auxiliary power. VLCCs currently use Heavy Fuel Oil
3) use of low-temperature LNG for:

- recovering Volatile Organic Compounds (VOCs), i.e. hydrocarbon gases from cargo oil which would otherwise be lost to the atmosphere. The recovered VOCs can be used as fuel in addition to LNG and marine diesel oil for auxiliary boilers producing steam for cargo pumps
- cooling scavenging air for the main engines
- engine cooling
- possibly also other functions like air conditioning, operating freezers, refrigerators, etc.

Throughout the project, the Triality VLCC has been compared with a conventional VLCC design from an environmental and economic viewpoint . The conventional design is used as the base case.

TRIALITY'S MAIN DIMENSIONS:

Length over all	361 m
Length betw. perpendiculars	351 m
Breadth over all	70 m
Depth	27.52 m
Draught at AP, loaded	22.2 m
Draught at FP, loaded	21.9 m
Draught at AP, unloaded	9.0 m
Draught at FP, unloaded	5.1 m
Block coefficient, loaded	0.60 -
Block coefficient, unloaded	0.52 -
Location of engine room bulkhead, in front of AP	50 m
Location of collision bulkhead, in front of AP	330 m
Cargo tank volume	358 000 m^3
Deadweight (0.799 t/m3 density crude)	291 300 tons
Lightship weight	50 600 tons
Service speed, loaded	15 kn
Service speed, unloaded	16.5 kn
Maximum range	25 000 nm



COMPARISON BETWEEN THE BASE CASE AND BALLAST-FREE VESSELS:

	BASE CASE VESSEL	BALLAST-FREE
Lpp	320	351
LOA	333	361
B	60	70
T design mean	21	21.6
T w/o cargo mean	9.8	6.3 (before updated steel weight)
Wetted surface w cargo	28 000	28 500
Wetted surface w/o cargo	20 000	13 000

Triality is wider and longer than a conventional VLCC, but still consumes less energy. This is due mainly to its reduced wet hull surface and consequently lower frictional resistance, but also to its improved hull shape (lower block coefficient).

OPERATING PROFILES

In order to measure the economic and environmental performance of the Triality VLCC, an operating profile representing the expected sailing patterns of both Triality and the baseline conventional VLCC is needed. With the forthcoming introduction of ECAs and the use of LNG as fuel, operating profiles based on historical data could prove to be inaccurate.

TEXT: **EIRIK FERNÁNDEZ CUESTA** AND **INGAR BERGH,** LOGISTICS CONSULTANTS, DNV proNAVIS

To address this, a realistic operating profile has to be constructed. A good operating profile must reflect the:
- characteristics of the crude oil market
- typical sailing and operational patterns of VLCCs
- availability of LNG for bunkering
- effect of the expansion of Emission Control Areas (ECAs)

CRUDE OIL MARKET AND TRADE LINES

The flow of crude oil export is decisive for the VLCC sailing pattern. Oil is the world's most traded commodity in terms of both value and volume. According to the US Energy Information Administration*), 83.7 million barrels of oil, approximately valued at USD 5 billion, were consumed daily in 2009. Roughly 60% of this had at some point been on board a ship. A considerable amount of this transport work is done by VLCCs sailing the world's major crude oil trade lines. These trade lines are depicted in Figure 1.

The majority of the VLCC routes originate in the Gulf. Figures issued by Clarksons suggest that as many as 75% of the routes start here and end in major markets such as East Asia, Europe and the US**). Of these, the Gulf – East Asia route is the dominant one, and its dominance

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Figure 1: VLCC trade lines (Source: Euronav Annual Report 2009)

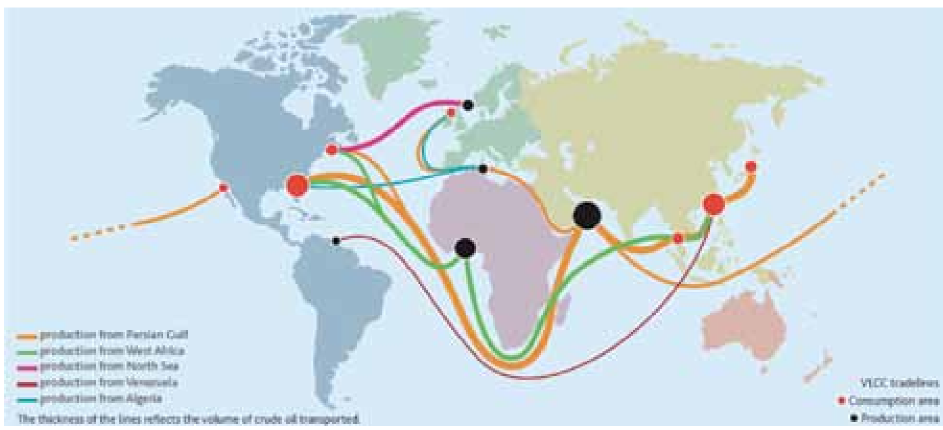

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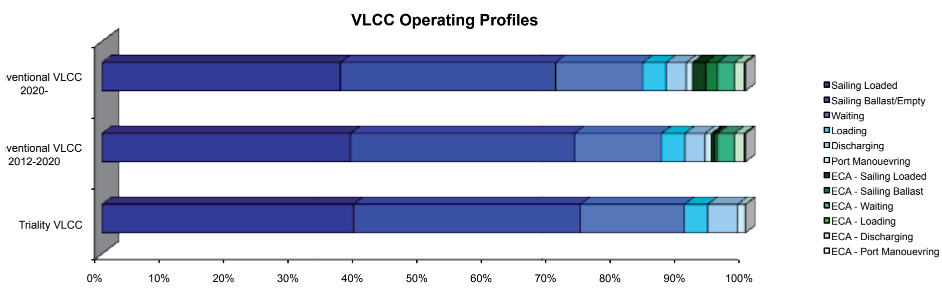
Figure 2: Operating profiles of VLCCs




Eirik Fernández Cuesta


Ingar Bergh

is expected to increase over the coming decades.

LNG BUNKERING There are currently very few LNG bunkering possibilities outside Northern Europe and none are suitable for a VLCC. Technically, it is fully possible to bunker from LNG storage tanks ashore or directly from an LNG feeder or bunker barge. The LNG fuel may be transferred via a flexible hose or a special rigid arm. Quite a few LNG production and export terminals exist in the Gulf area. These are excellent sources for local LNG fuel distribution. The distribution of LNG as fuel is now being studied in various other places in the world and is expected to develop gradually over the next few years. In our study, the current bunkering of LNG is assumed not to affect the VLCC's operating profile to any large extent.

Practical alternatives for LNG bunkering include:

- Bunkering from an LNG feeder/barge that is docked alongside the VLCC while the VLCC is at the loading/discharging terminal or at sea/anchor. Such operations must be carried out according to the instructions of the terminal or port authorities.
- Bunkering from land-based LNG storage tanks (at the oil terminal). The vessel is in such case berthed at an oil terminal and bunkering from a shore-based LNG bunker tank which is filled from LNG feeders or bunker barges.

EMISSION CONTROL AREAS

The future introduction of ECAs has no impact on the operating profile of the Triality VLCC as the vessel runs on LNG. However, this will impact the operating profile of conventional VLCCs as these vessels will need to either use a scrubber or perform a fuel switch to meet the ECA requirements. The North Sea is already an ECA and the sea off the coast of North America will become one in 2012. In addition, the Mediterranean Sea and port of Singapore will probably become ECAs in 2020.

OPERATING PROFILES

In order to create the operating profiles, three representative routes were chosen from among the major ones and weighted to make one overall operating profile for Triality. The chosen routes were the Gulf - East Asia weighted by 65%, the Gulf – US weighted 20% and the Gulf – Europe weighted 15%. The Triality's operating profile was then calculated using information about typical port waiting times, port manoeuvring times and the time taken to load and discharge cargo in each port. Similarly, the operating profile for a conventional VLCC with the same sailing pattern was estimated after taking the ECAs into account.

Figure 2 shows that the conventional VLCCs are expected to spend 5% of their time in an ECA from 2012, a figure that is expected to increase to around 8% after 2020. In addition, the emission requirements within the ECAs will become stricter with time. Because Triality is LNG fuelled, it does not have to perform a fuel switch or scrub its exhaust gas to meet the emission requirements. This contributes significantly to the Triality's favourable performance. ○

**) Source: http://www.eia.doe.gov/oil_gas/petroleum/info_glance/petroleum.html*
***) Source: www.clarksons.net*

Natural gas fuelled VLCC

Two large deck tanks inside deck houses on the tank deck are the most visible difference between a conventional VLCC and Triality. But the resulting emissions reductions are even more remarkable!

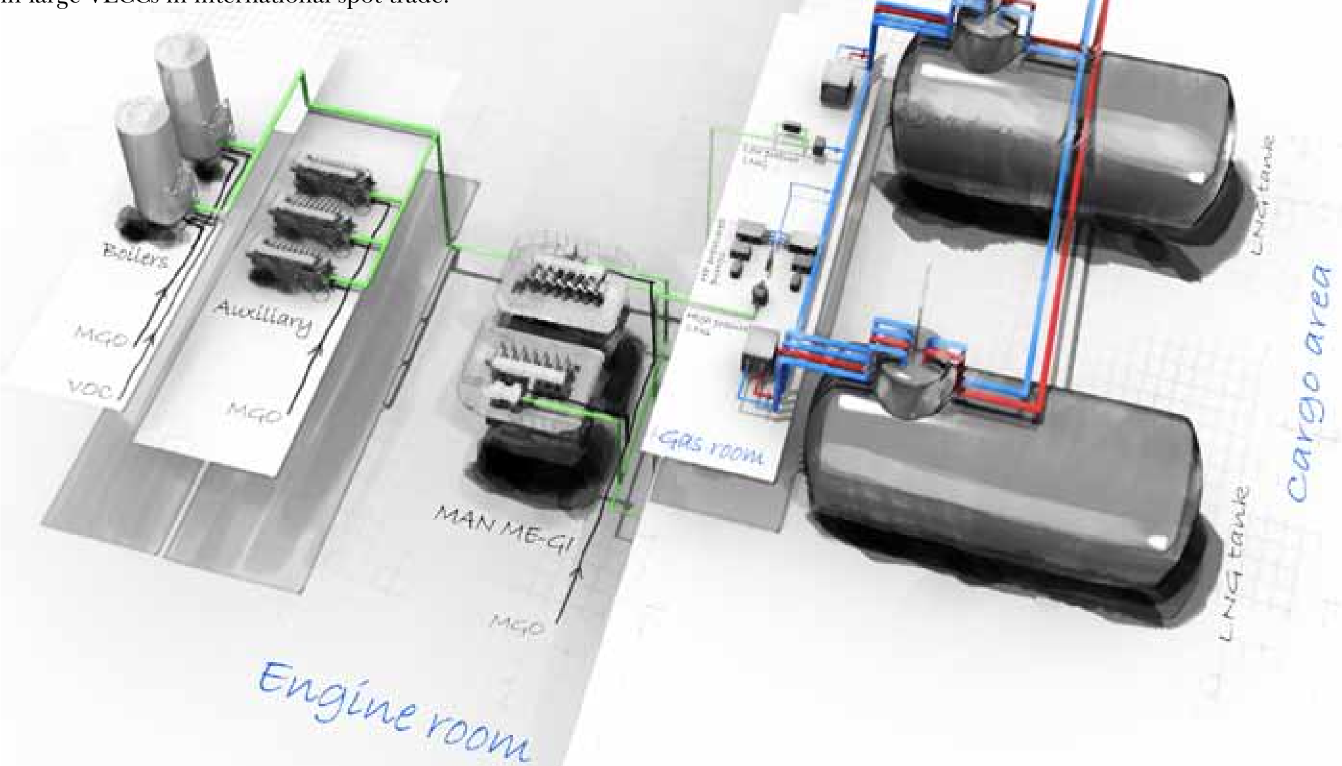
TEXT: **TORILL GRIMSTAD OSBERG,** TRIALITY PROJECT MANAGER, DNV

LNG AS A SHIP FUEL - NOT REALLY ANYTHING NEW

Liquefied natural gas (LNG) has already proven viable as a ship fuel. There are now a number of ships in operation using LNG as fuel, and a lot more are on the way. Apart from gas carriers, these ships mainly operate in Norway and are primarily smaller ships in local trade. As the class society that has approved all the gas-fuelled ferries, cargo ships, coast guard vessels and so on this far, DNV has played a central role in the development process. However, although LNG as a fuel is no longer a novel technology, some new solutions are necessary when introducing LNG in large VLCCs in international spot trade.

ENOUGH LNG FUEL CAPACITY FOR A TRIP AROUND THE GLOBE

The two impressive 6 750 m^3 liquefied natural gas (LNG) tanks are the most visible difference compared to the smaller LNG-fuelled ships. The LNG capacity is enough for 25 000 nautical miles of operation. This gives the same operational flexibility as other VLCCs, and is enough for a round trip from the Gulf to the US without re-fuelling. In comparison, the circumference of the Earth at the equator is about 22 000 nautical miles. VLCCs have a lot of space available on the cargo deck and this is where we have placed the tanks. They are located about 10 metres from the ship side and their outside insulation is protected by the surrounding deck houses. The deck houses also provide the added benefit of protecting the tanks from, for instance, a cargo deck fire or impact. The insulated pressure tanks can accumulate boiled-off gas for several days without any need for a re-condensation system even if gas from the tanks is not consumed. This type of tank (called IMO type C) is reliable and results in very simple fuel system operations since the pressure in the tank



can be used to transfer the gas to consumers on board. All the tank connections lead from the domes on top of the tanks to a separate fuel gas room where the necessary process equipment is located. Other tank types have also now been developed for use as LNG bunker tanks - prismatic tanks can provide better space utilisation in ships where space for LNG is limited. However, a lack of space is not a problem on VLCCs.

HIGH EFFICIENCY MAIN ENGINES AND NO MORE HEAVY FUEL OIL

The second difference compared to the smaller gas-fuelled ships is that we have introduced large two-stroke dual fuel main engines. This engine type will soon be available from MAN Diesel & Turbo and has the same high efficiency as other two-stroke engines, burning natural gas with a pressure of 300 bar and using fuel oil for ignition. We have developed two versions of the LNG-fuelled VLCC, one of which has a conventional VLCC hull while the other has the new ballast-free hull. The natural gas installations are the same, but the conventional hull has one main engine with a fixed pitch propeller while the ballast-free ship has two main engines and propellers because of the reduced draft in an unloaded condition.

The generator engines are designed for lean burn dual fuel operation and low pressure gas. Such four-stroke engines may also be an option as main engines for the Triality ship with two main engines, but they have not been particularly developed for direct mechanical operation. The lean burn four-stroke engines have the advantage of directly meeting even the strictest NOx emissions requirements for ships built after 2016 (Tier III) but are slightly less efficient. The two-stroke gas engines also directly reduce NOx emissions by about 13% compared to oil-fuelled engines, but not down to Tier III levels. According to MAN Diesel & Turbo, however, the necessary reduction to comply with Tier III can be obtained by using exhaust gas recirculation.

In addition, the auxiliary steam boilers can burn natural gas but also have the option of burning fuel oil or VOC (see separate chapter about our VOC emissions reduction solution).

Low sulphur marine gas oil is used as pilot fuel in the main engines for ignition and back-up fuel. This means that even when the two-stroke main engines have to switch off gas operation below 25% loads, the emission control area (ECA) sulphur level requirements can be met. The machinery can also operate fully on fuel oil. The project has assumed that the ship will burn gas in all normal operation modes except during low load situations. Full back-up fuel oil capacity is therefore not included.

The above concept also has the great benefit that the complex heavy fuel oil installation normally used in VLCCs is omitted.

›› Triality has two large two-stroke dual fuel main engines (MAN).

HIGH AND LOW PRESSURE GAS SUPPLY SYSTEMS

The gas supply systems for the high pressure main engines and low pressure consumers are different. Liquefied natural gas has a temperature of about -140°C at 5 bar pressure, which is about the pressure maintained in the tanks. This pressure is sufficient to send liquefied gas to the high pressure pumps, delivering liquid with 300 bar pressure to the high pressure vaporizer, which in turn delivers gas with a temperature of 45°C to the main engines. The high pressure pumps are energy efficient and the energy consumption is comparable to that of regular high pressure pumps on a diesel engine.

The low pressure system has no moving parts - the tank pressure pushes the liquefied gas through the low pressure vaporizer and on to the consumers. Pressure build-up units are heat exchangers used to regulate the tank pressure. The loop is operated automatically to keep the pressure in the tanks within the preset value of 5-6 bar that is needed for the supply to the consumers.

Each tank is also equipped with a submerged pump; this can be used to transfer LNG from the tanks when the tanks are not pressurised.

ENVIRONMENTAL BENEFITS

The emissions reductions gained from switching to natural gas as fuel are first of all an impressive 94% reduction in SOx and particles emissions since LNG is sulphur-free. Natural gas, which mainly contains methane, has less carbon per energy content than oil fuels and therefore emits less CO_2 when burned. On the other hand, methane itself has a greenhouse gas potential that is 21 times higher than CO_2, and four-stroke gas engines emit some unburnt methane, called methane slip. This eliminates some of the positive effects of the CO_2 emissions reduction. The two-stroke main engines used in our project do not have a methane slip problem due to a different engine cycle. Some gas will still be released from the piping system during operation, but this is little compared to the 24% CO_2 reduction due to the combustion of natural gas instead of heavy fuel oil.

THE BALLAST-FREE SHIP

A conventional VLCC uses ballast water for two different parts of its operations. In unloaded transit condition, the ballast is needed to obtain both a fully submerged propeller and enough forward draft to avoid bottom slamming. During cargo operations, ballast water is used to reduce bending moments and compensate for trim and heel.

TEXT: **HÅVARD NORDTVEIT AUSTERFJORD** AND **SERGE SWALENSTOCKER**, DNV


Håvard Nordtveit Austerfjord


Serge Schwalenstocker

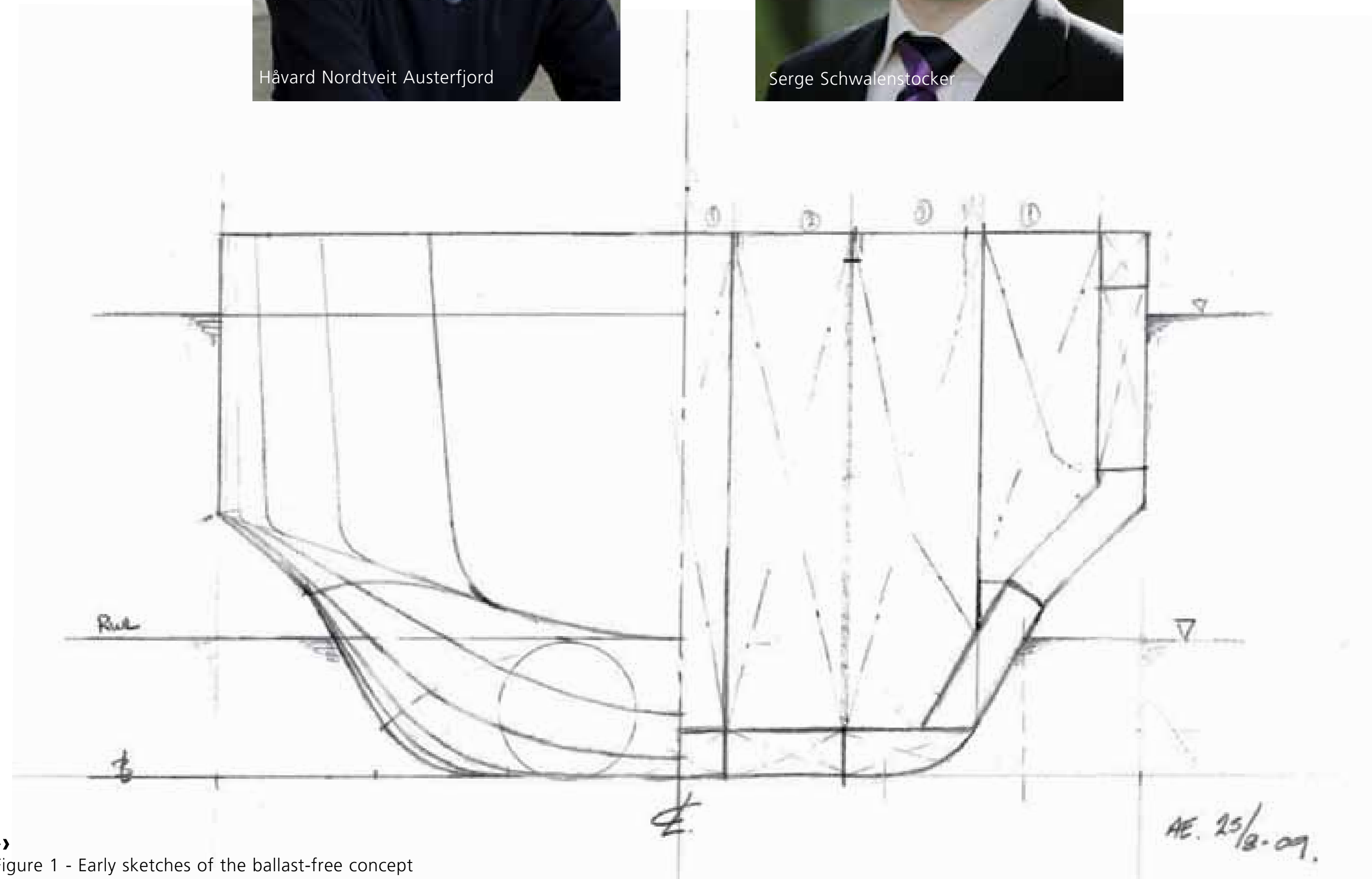


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Figure 1 - Early sketches of the ballast-free concept

A tanker's ballast operations give rise to two main unwanted effects:

- ballast water contains organisms that can cause damage when released to foreign ecosystems
- additional fuel is needed to transport the ballast water

Triality's tank arrangement and hull shape eliminate the need for ballast in its operations.

BALLAST-FREE HULL SHAPE

In order to have a ballast-free VLCC, some drastic changes in the hull form are needed. A conventional 300k DWT VLCC in lightship condition will typically float with a mean draft of 3-4 metres - with the bow and propeller almost out of the water. To increase the draft in lightship condition, a more V-shaped hull has been developed for our concept ship.

Our concept ship is designed to carry a certain volume of cargo. The main target during the hull design phase was to minimise the resistance and optimise the propeller conditions.

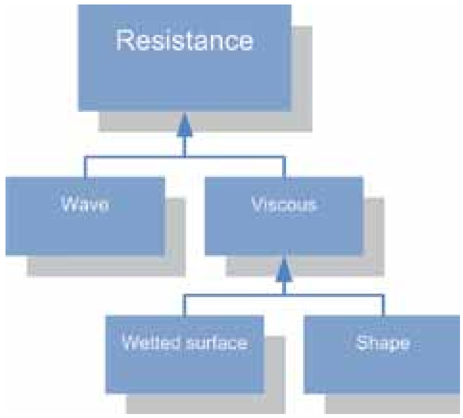
Figure 2 shows that a ship's resistance is typically divided into viscous and wave-making resistance. Wave-making resistance becomes important when the speed increases. Traditional VLCCs operate at moderate speeds and their resistance is dominated by viscous effects. The viscous effect is proportional to the vessel's wetted surface and a shape factor which depends on the hull geometry.

Our main focus was on minimising the weighted sum of the wetted surface in fully loaded and unloaded conditions. Triality will spend approximately the same time in loaded and unloaded conditions and these have therefore been weighted evenly. This optimises the total resistance of the complete voyage.

A box-shaped parametric hull was created to minimise the wetted surface for the required displacement. The following parameters for the submerged part of the vessel may be varied:

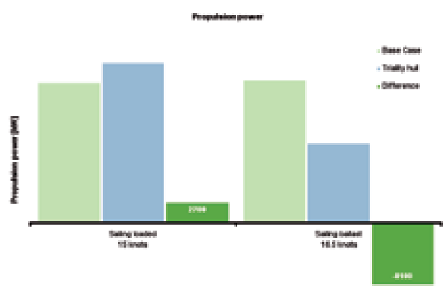
- Draught
- Breadth on keel
- Breadth
- Height of vertical side
- Length

These parameters can result in anything between a wedge and a conventional hull. A wide span of parameters was analysed in order to find the least wetted surface. An illustration of the new cross section is shown in figure 3.



›› Figure 2: Important resistance components

›› Figure 3: Cross sections for Triality and a conventional VLCC



›› Figure 4: Propulsion power

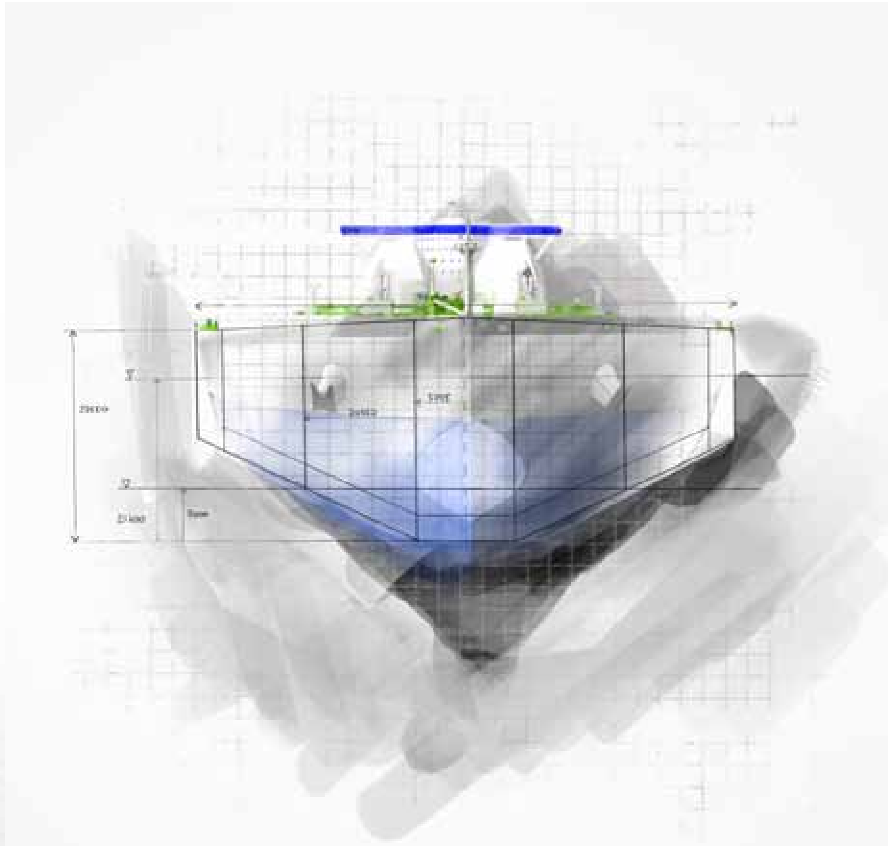
ESTIMATED VISCOUS RESISTANCE

Computational Fluid Dynamics (CFD) is a viable alternative with full-scale prediction accuracy on a par with scaled model test results. In many cases, the numerical simulations surpassed the towing tank estimates in accuracy. Simulations have significant advantages in terms of cost and flexibility. Numerical simulations take significantly less time to set up than experiments.

By using CFD tools, we could compare the viscous resistance of the new design with that of a more traditional design. There was a focus on optimising the pressure fields in the bow and stern area. High pressure areas in the bow and low pressure areas in the aft contribute to a bad shape factor and should be avoided. Several iterations of redesign and CFD analyses led to the final hull shape.

PROPULSION

The optimum diameter and twin screw propellers will allow for a low draught aft in the unloaded condition. At the same time, high propulsive efficiency is ensured by the overlapping propeller arrangement. The ship wake caused by friction between the ship's hull and the surrounding water is focused near the centreline (similar to conventional single screw ship designs). This represents a loss of energy which is partly recovered by the propellers, as both of them will contribute to a re-acceleration of the ship wake. Additionally, the two propellers have the same direction of rotation, and the overlap arrangement will contribute further to a reduction in rotational energy losses compared to a conventional arrangement.



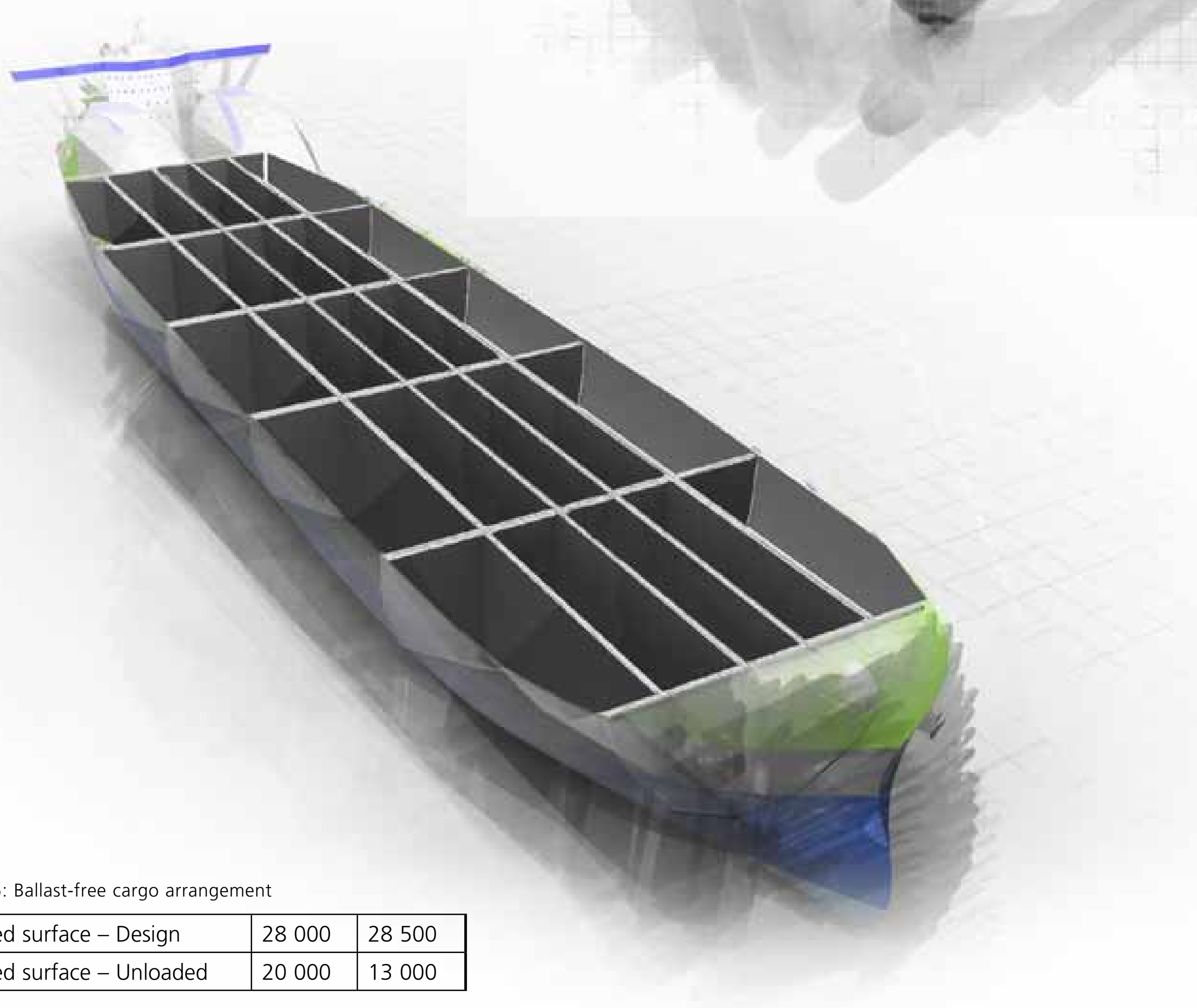


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Figure 5: Ballast-free cargo arrangement

Wetted surface – Design	28 000	28 500
Wetted surface – Unloaded	20 000	13 000

PROPULSION POWER

Propulsion power estimates are based on the resistance and propeller analyses. Figure 4 shows a comparison between Triality and a conventional tanker. The conventional tanker needs less propulsion power in full load condition while Triality reveals its potential in the unloaded condition.

SUMMARY OF KEY FIGURES

Table 1 shows some comparisons of key figures for Triality and the conventional VLCC.

	Base case	Triality
Wetted surface – Design	28 000 m^2	28 500 m^2
Wetted surface – Unloaded	20 000 m^2	13 000 m^2
Draft – S.G. 0.799	21.0 m	21.5 m
Draft – S.G 0.875	22.5 m	23.0 m
Draft – Unloaded	10.0 m	6.5 m
Propulsion power – Design	18 MW	21 MW
Propulsion power – Unloaded	18 MW	10 MW
Block coefficient – Design	0.80	0.53
Block coefficient – Unloaded	0.75	0.62

››
Table 1 Key figures for Triality versus the conventional VLCC

BALLAST-FREE TANK ARRANGEMENT

An important criterion for the new design is that it must be possible to carry out the cargo handling process without ballast water, using existing infrastructure and in accordance with prevailing regulations.

A traditional VLCC will arrive at the cargo terminal with full ballast tanks and empty these while filling the cargo tanks to avoid high bending moments, list or trim during the cargo operations.

Since Triality does not carry ballast water, the ship's internal arrangement needs to be such that it will inherently compensate for bending moments, trim and heel.

The solution to compensate for these elements is a cargo arrangement divided into five longitudinal cargo sections, one centre tank, two intermediate tanks and two side tanks. This is achieved by having four longitudinal bulkheads instead of the two that are common on conventional tankers.

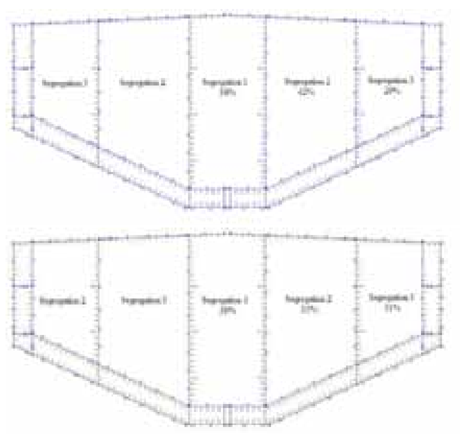

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Figure 6: Longitudinal cargo segregations

LONGITUDINAL BENDING MOMENTS

By filling/emptying a cargo section along its entire length, no longitudinal bending moments occur due to uneven cargo weight along the length of the ship. Triality will be equipped with a cargo piping arrangement that is set up for filling/emptying a complete longitudinal cargo section simultaneously.

TRIM AND HEEL

To avoid large heeling angles during cargo operations, the cargo must be prevented from causing heeling moments on the ship. Heeling moments are avoided by placing the longitudinal bulkheads to give moment equilibrium around the longitudinal centre line for all segregation alternatives. Moment equilibrium occurs not only when side or intermediate tanks on both sides are filled with the same segregation, but also when a side tank on one side is filled at the same time as an intermediate tank on the opposite side of the vessel is filled.

By filling cargo along the full length of the cargo section, no large trims will occur during the cargo operations.

CARGO SEGREGATIONS

The given tank configuration results in a segregation share of:

- Segregation 1: 55%
- Segregation 2: 25%
- Segregation 3: 20%

Or

- Segregation 1: 55%
- Segregation 2: 22.5%
- Segregation 3: 22.5%

With regard to cargo segregations, Triality may in principle be loaded in the same way as a conventional crude oil carrier as long as the transverse equilibrium and longitudinal filling along the complete length are maintained. ○

Additional benefits from LNG fuel:

Using low-temperature LNG to increase efficiency and minimise cargo losses to the atmosphere

TEXT: **TORILL GRIMSTAD OSBERG,** TRIALITY PROJECT MANAGER, DNV
AND **JAN KOREN,** SEGMENT DIRECTOR TANKERS, DNV

RECOVERY OF VOLATILE ORGANIC COMPOUNDS (VOCS)

Hydrocarbon gases evaporate from crude oil into the cargo tank atmosphere, particularly in connection with cargo loading, laden voyages and tank cleaning (crude oil washing – COW) after discharge. These hydrocarbons are frequently referred to as Volatile Organic Compounds – VOCs. The release of VOCs from the crude oil depends on different factors such as the chemical composition, temperature, pressure drops in cargo piping, pressure in the tank atmosphere, liquid movements of free oil inside tanks, etc.

VOCs are vented to the outside atmosphere to protect the tank structure from overpressure when pressure builds up. Such venting may also take place during the return voyage to the loading terminal due to heating and the associated pressure increase inside the tank caused by sunshine.

The volumes of cargo (VOCs) lost to the atmosphere are significant, representing economic losses to cargo owners. This also has a negative environmental impact. There is a greenhouse effect and VOCs can react with NOx in sunlight to create ozone. Ozone in the lower atmosphere is an air pollutant that has harmful effects on respiratory systems and also burns sensitive plants. In other words, there are good reasons to search for feasible alternatives to limit VOC emissions to the atmosphere.

Estimates prepared by Marintek in Norway and others indicate that approximately 500-600 tons of VOCs may be lost from a VLCC during voyage, i.e. around 0.2% of the cargo carried. On a global scale, these yearly VOC releases from oil carriers to the atmosphere have been estimated to be more than 5 mtons. The losses are basically the light ends of crude oil, which are the most valuable fractions.

The cargo losses outlined above have traditionally been accepted by cargo owners and most regulators. Since 1 July 2010, a ship-specific VOC Management Plan, approved by the Flag Administration, has been required for oil carriers according to MARPOL Annex VI. The practical reductions of VOC emissions as a consequence of this are believed to be quite limited. Only operational procedures with no emission limitations have been specified, and no hardware installations are required.

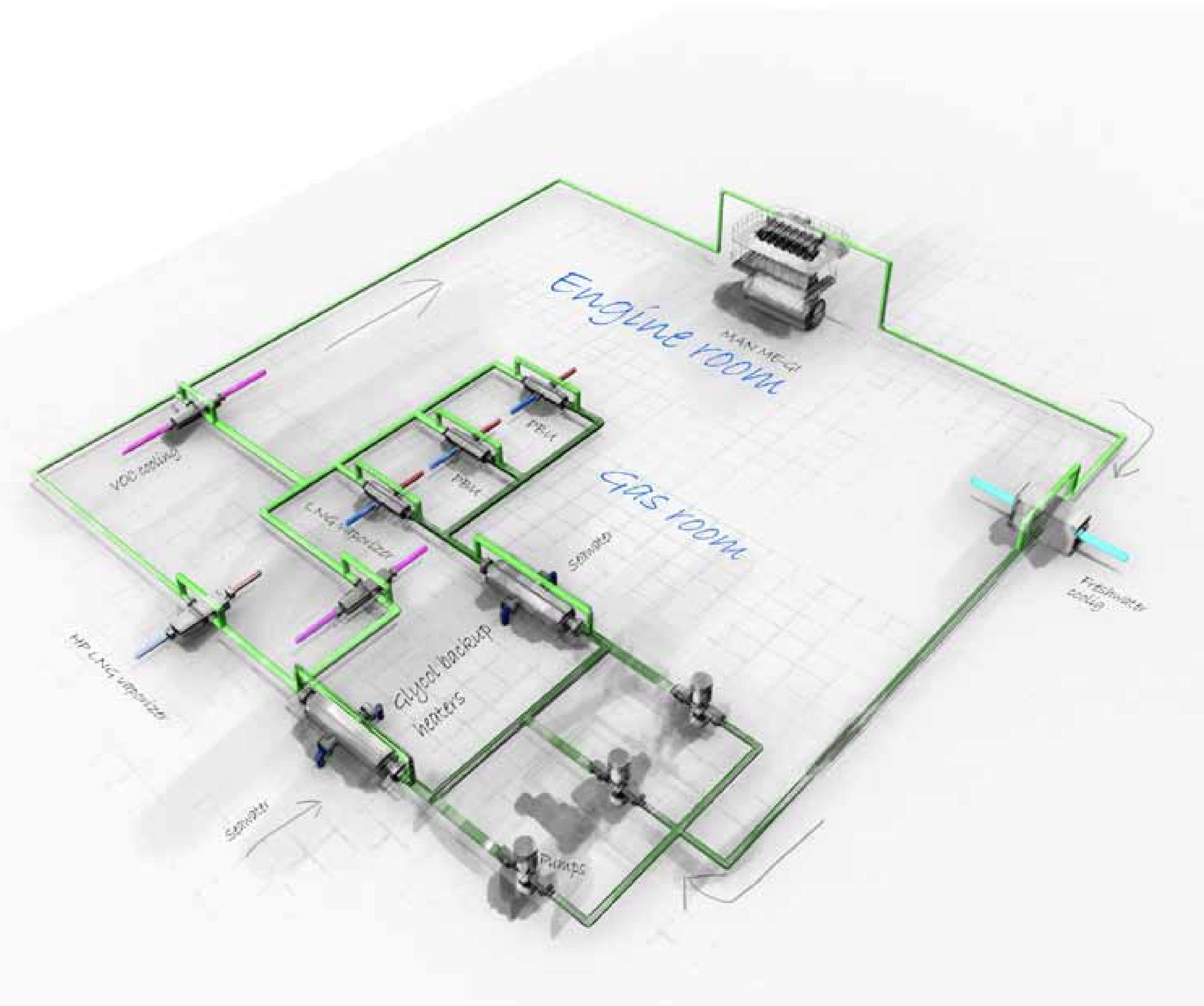
One of Triality's main features is the recovery of VOCs, which are collected in separate tanks and used as fuel for auxiliary boilers producing steam for the cargo pumps.

According to the Triality concept, a vapour return line taking care of most of the VOCs otherwise released to the atmosphere during loading is assumed to be arranged at the terminal, as the loading rate is often in the range of 20 000 m^3 per hour. Oil tankers built today are required to have a vapour return line installed on board, while it is up to the shore side to arrange and operate the return line to handle the VOCs from the loading tanker. Although only a limited number of loading terminals have arranged such return lines so far, more are expected to do so in the near to medium term.

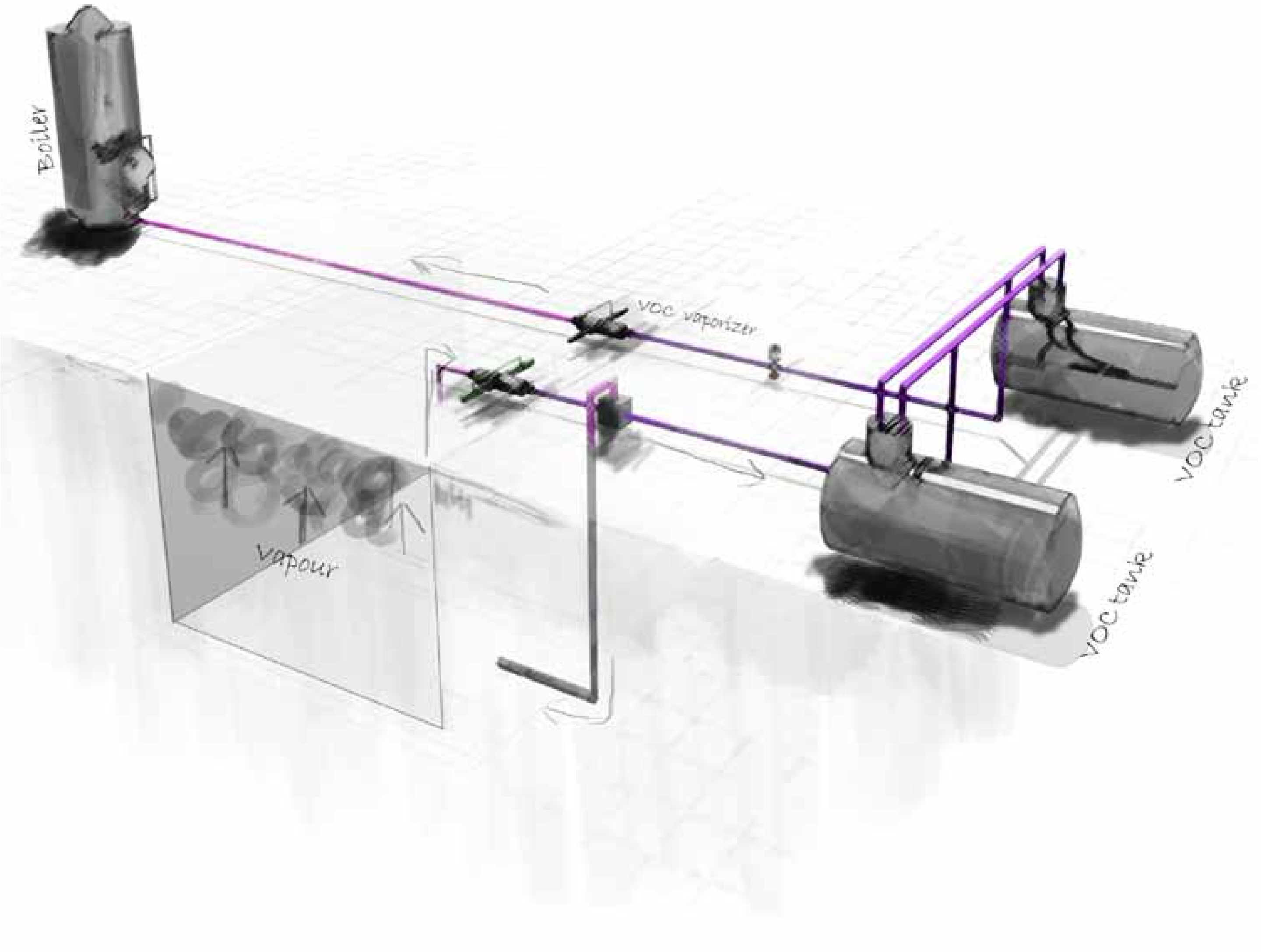
VOC recovery arrangements on board Triality are assumed to take care of all VOCs otherwise released to the atmosphere, during voyage. What is not recovered on board is then assumed to be returned to the terminal installations via the vapour return line.

The LNG needs to be heated, i.e. re-gassed, before being used as fuel for the engines. Significant amounts of "cooling energy" need to be supplied to the vaporizers, where the LNG is re-gassed, for this purpose. Such energy exists in abundance on board an LNG fuelled tanker, and is assumed to be available relatively easily, based on arrangements indicated in

Don't underestimate the value of cooling. The scavenging air cooling may provide an energy efficiency gain of up to three per cent.



Triality uses the low LNG temperature to capture cargo vapours otherwise lost to the atmosphere. This reduces the annual fuel consumption by eight per cent.



the figure on page 19. The result will be energy efficient re-gassing of the LNG combined with energy efficient recovery of VOCs.

All the vaporizers and pressure build up units (PBUs) are connected to a glycol circuit which is connected to different heat exchangers where the low temperature is removed.

The first such heat exchanger in the glycol circuit is the VOC re-condenser. Hamworthy Gas Systems has for years delivered VOC re-condensation plants for shuttle tankers doing bow loading in the North Sea. These installations are large scale for cargo loading capacity and relatively complex, including big cooling plant installations with compressors, heat exchangers, separators and so on. Simpler and less resource demanding installations will be welcomed.

For VOC re-condensation during cargo voyages and cargo discharges, only a small-scale plant is needed and many compressors and much of the complexity can be avoided when using the glycol from the LNG heating instead of a separate cooling circuit. Such a VOC recovery installation is consequently simpler and has few moving parts - only a small compressor and the glycol pumps have to be present in any case.

The VOC re-condensation starts when the pressure in the tanks rises above a preset limit and stops when the pressure drops below a certain low limit. The liquid VOCs (propane, butane and heavier components) are collected in dedicated deck tanks for this purpose. Lighter fractions of the gas which cannot be condensed (methane) as well as inert gas are returned to the cargo tanks - no vapour is released to the air.

The recovered VOCs are intended to be burned in special triple fuel burners in the auxiliary boilers, producing steam to operate cargo pumps. Should the recovered VOCs exceed what is needed for the boilers, the excess volume can be transferred back to the cargo where the VOCs originated.

It may also be possible to burn VOCs in the highly efficient two-stroke dual fuel engines. They would in such case have to be compressed to a higher pressure than natural gas. However, the ignition properties are different. These will also vary from cargo to cargo as the compositions of crude oils are different, representing a risk of knocking and other problems. This alternative has therefore not been further evaluated for Triality.

The mandatory inert gas lines on deck and piping to a mast riser installed on board may be used to supply VOC gases to the recovery system.

USE OF LNG FOR OTHER COOLING PURPOSES

The low-temperature LNG can also be used for purposes other than the recovery of VOCs as outlined above. The cooling of scavenging air to the engines to improve engine efficiency, engine cooling, air conditioning and the operation of freezers and fridges are all purposes which will improve energy efficiency and are assumed to be cost effective.

The second heat exchanger in the glycol circuit after the VOC re-condenser in the figure above is for cooling the scavenging air. According to MAN Diesel & Turbo, up to 3% more engine efficiency can be gained when the air into the main engine is cooled to 10°C.

The third heat exchanger is connected to the FW cooling of the machinery. And if the temperature is still too low, sea water heaters are provided before the vaporizers.

Each element in the system is equipped with a temperature-controlled bypass loop in order to regulate its heat exchange.

The glycol system temperature must be kept above -40°C to avoid freezing. Since the LNG going through the vaporizers is under high pressure, this will have to be taken into account in the detail design of the system. The system will also have to be designed such that humidity does not freeze in the recovery system and stop the VOC recovery function.

The environmental benefits of using LNG will increase in importance over time

TEXT: **SOFIA FÜRSTENBERG,** CLEANER ENERGY, DNV, SINGAPORE

THE COMPETITIVENESS OF LNG VS. FUEL OIL WILL IMPROVE WITH STRICTER ENVIRONMENTAL REQUIREMENTS

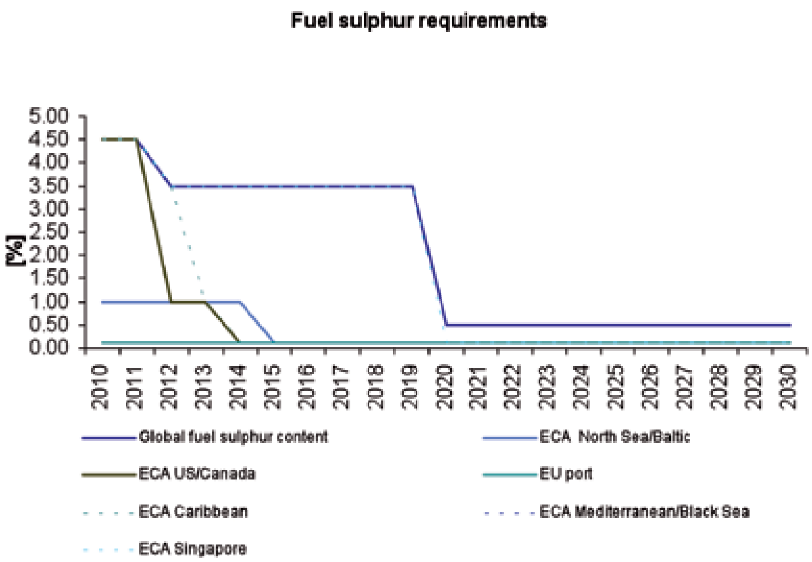
As the regulatory landscape on environmental performance requirements is becoming increasingly tight, a shipowner's level of freedom is being gradually restricted. In 2020, the global fuel sulphur requirements are set at 0.5%, which will imply a significant increase in fuel costs. It may even be questioned whether the low-sulphur fuel supply is able to meet demand.

In order to comply with these stricter fuel requirements, shipowners have three alternatives to consider:

a) Shift to low-sulphur fuel
b) Implement SOx-scrubbing
c) Shift to LNG fuel

When evaluating Triality's cost-benefit and operational performance from an environmental perspective, the base case VLCC has been fitted with a seawater SOx scrubber for both the main engine, auxiliary engines and boilers. The performance has been evaluated for 2015, when the North American ECA will be enforced and stricter NOx regulations will apply to the North Sea and Baltic Sea ECAs.

In 2015, stricter environmental regulations will be enforced, particularly for ECAs and EU port operations. With the global cap being introduced in 2020, the benefit of LNG compared to fuel oil will become even greater; however that particular study is not presented here.



›› Figure 1 Sulphur emission requirements

›› Figure 2 North Sea ECA and Baltic Sea ECA

›› Figure 3 North American ECA

The costs of operating a seawater SOx scrubber for a VLCC are significant

When assessing the benefit of LNG over fuel oil, the added fuel cost for the seawater SOx scrubbing is of obvious interest. The size of the ship will determine the water capacity needed and the associated required pump capacity.

For a ship of VLCC size, the collective footprint is typically as follows:

SOx scrubber	Height [m]	Length [m]	Width [m]	Dry weight [ton]	Running weight [ton]
Main engine	3.5	6.2	10.9	6.3	8.8
Auxiliary	3.9	3.9	7.6	5.5	7.3
Boiler	2.9	5.3	8.9	5.6	7.9

›› Table 1 – SOx scrubber footprint [Hamworthy/Krystallon]

For operations in ECAs in 2015, when a fuel sulphur limit of less than 0.1% will apply, the added fuel consumption from SOx scrubbing is as much as 4% for a VLCC. However, the ship will spend little operational time within an ECA so the annual fuel penalty for the studied route will not be substantial. The picture will look different in 2020, though. With a global cap of 0.5% in 2020, the added fuel consumption will be 3.6% of the total annual fuel consumption, which is definitely significant.

THE TRIALITY DESIGN SOLUTIONS IMPLEMENTED FOR THE ENTIRE VLCC FLEET WOULD RESULT IN A 33% REDUCTION IN CO_2 EMISSIONS

The annual reduction in CO_2 emissions for a VLCC that shifts to the Triality design is 25 100 tons. Taking into account the improved hull design, the removal of ballast water and the cooling of scavenging air by the LNG vaporization process, the CO_2 emissions will be reduced by a total of 33%.

The seawater scrubbing of exhaust in the base case will accomplish a significant removal (up to 80%) of particulate matter (PM) in addition to SOx. As seawater scrubbing adds a fuel penalty, the scrubbing capacity has been adjusted to meet current requirements. The maximum SOx scrubbing capacity is typically 95-99%. For this study, it was assumed that LNG fuel does not produce any particles. Triality accomplishes a 94.5% reduction in SOx emissions, or an annual removal of 1 540 tons. For particulates, this figure is 93.5% or 187 tons.

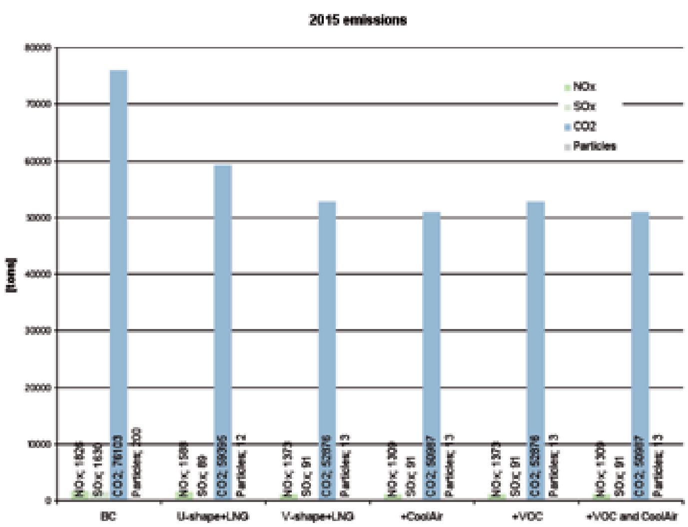
For ships constructed on or after 1 January 2016, operations inside an ECA will require reduced levels of NOx emissions in accordance with the IMO NOx Technical Code Tier III. The limits are decided based on engine particulars and, for the VLCC case, this translates into a required reduction from max 14.4 g/kWh today to max 3.4 g/kWh in 2016.

Triality is assumed to be built before 2016; hence compliance with IMO NOx Technical Code Tier III is not necessary.

With the Triality design, a 28.5% NOx reduction is accomplished, equal to an annual reduction of 520 tons. It is possible, however, to include Exhaust Gas Recirculation on Triality. The EGR technology provided by MAN would further reduce the NOx emissions by more than 50%, resulting in a total NOx reduction of 82%.

In 2008, the VLCC fleet consisted of 504 ships. If the base case emissions are multiplied by the total VLCC fleet, this gives a theoretical estimate of the environmental footprint, in terms of emissions to air, of the entire VLCC fleet, which again indicates the potential for improvements.

The theoretical case of changing the existing VLCC fleet into ships built according to the Triality design would have a noteworthy impact in a world-fleet perspective too. The improvement is particularly interesting for SOx and PM emissions, both of which achieve a relative improvement of more than 6% in relation to the entire international world fleet. ⭘



‹‹ Figure 4 – Total emissions in 2015

Is it possible to go green and be profitable?

TEXT: **HENRIK LARSÉN** AND **OLE EIVIND SKAAR,** DNV

The shipping industry is facing an increasing demand to reduce its environmental footprint. For ships built before 2016, the present challenge is to comply with ballast water and emission requirements. For a conventional VLCC burning heavy fuel oil (HFO), installing an exhaust gas scrubber and a ballast water treatment system (BWTS) are possible ways to address these issues.

We have demonstrated that Triality has a significantly smaller environmental footprint than a conventional VLCC that burns HFO and has a BWTS and exhaust gas scrubber installed on board.

The question then is: is it possible to go green and be profitable? The short answer is yes – Triality is more profitable than a conventional VLCC.

The financial analysis (investment cost versus voyage costs for different fuel price scenarios[1]) shows that Triality:

- improves the expected present value before tax by MUSD 24 in the reference fuel price scenario (This corresponds to around 20% of the investment cost in a conventional VLCC)
- is profitable until the LNG price reaches USD 15 per MMbtu (≈ 710 USD/ton LNG) in the reference oil price scenario
- is more profitable than the conventional VLCC except in the low oil price scenario
- has a higher expected present value before tax than the conventional VLCC in 92% of cases

These points are substantiated below.

TRIALITY IMPROVES THE EXPECTED PRESENT VALUE BEFORE TAX BY MUSD 24 IN THE REFERENCE FUEL PRICE SCENARIO

Over a 20-year period, Triality improves the expected present value by MUSD 24 compared to the conventional VLCC in the reference fuel price scenario. Figure 1 shows how the Triality cost structure differs from that of a conventional VLCC. In short, Triality increases the initial investment by MUSD 14 and reduces the voyage costs by MUSD 38.

TRIALITY IS PROFITABLE UNTIL THE LNG PRICE REACHES USD 15 PER MMBTU IN THE REFERENCE FUEL PRICE SCENARIO

Triality is profitable with an LNG price of up to USD 15 per MMbtu given the reference oil price scenario. Given high and low oil price scenarios, the expected break-even price is USD 26 and USD 6 per MMbtu respectively. Figure 2 shows the difference in present value before tax (ΔPV b.t.) between Triality and the conventional VLCC as a function of the LNG and oil price.

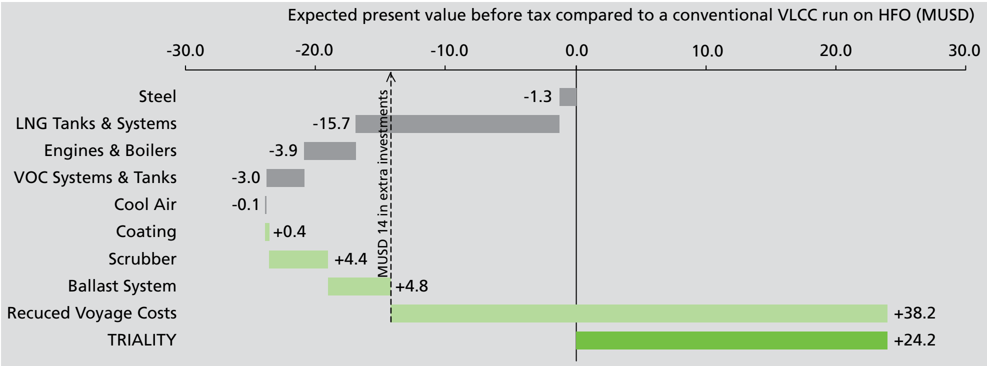
TRIALITY IS MORE PROFITABLE THAN THE CONVENTIONAL VLCC EXCEPT IN THE LOW OIL PRICE SCENARIO

So far we have mainly discussed the financial performance given the reference fuel price scenario. However, there are major uncertainties connected with fuel price developments. Figure 3 gives a more detailed view of fuel price scenarios, present values and the payback time on marginal investment (MUSD 14). Triality is more profitable than the conventional VLCC in the Reference (R) and High (H) oil price scenarios irrespective of the LNG price scenario. The present value before tax is MUSD 9-129. The payback time on marginal investment is 6-16 years.

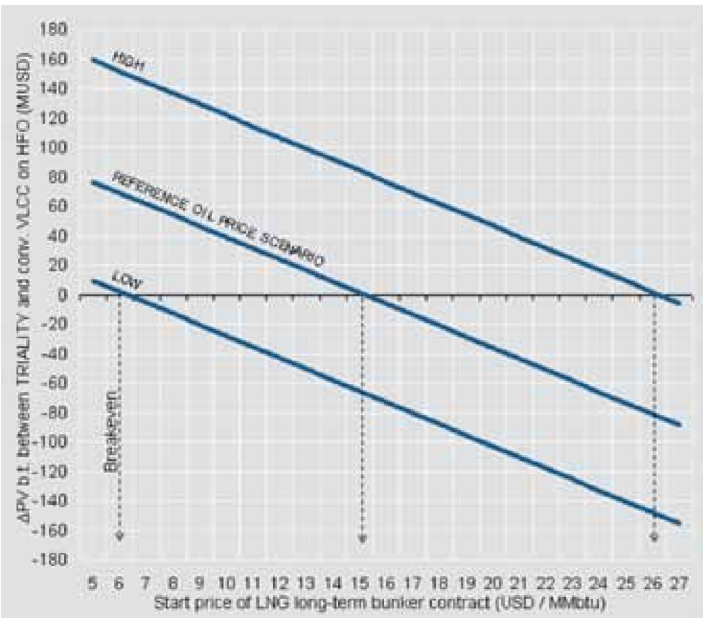
TRIALITY HAS A HIGHER EXPECTED PRESENT VALUE BEFORE TAX THAN THE CONVENTIONAL VLCC IN 92% OF THE CASES

To make a qualified decision, an investor needs to understand how the uncertainties in fuel price and investment costs influence financial performance. Figure 4 shows that Triality has a higher expected present value before tax than the conventional VLCC in 92% of cases. An important reason for the robustness of Triality's profitability is the reduced price uncertainty stemming from the LNG long-term bunker contract.

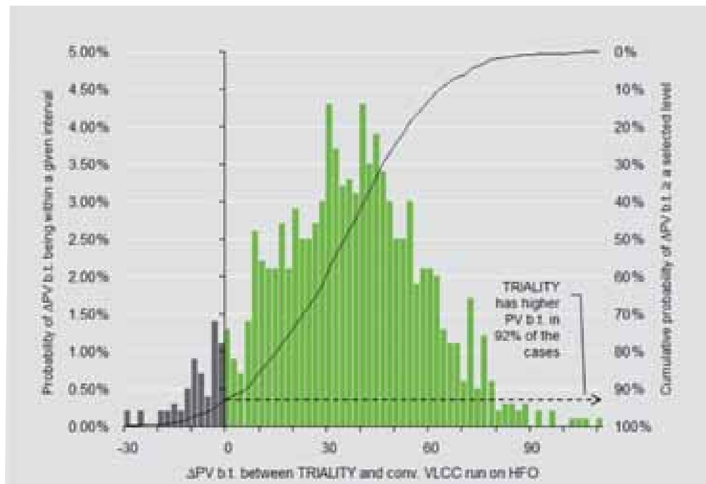
[1]Fuel price developments are a major uncertainty when evaluating voyage costs. In this study the U.S. Energy Information Administration's (EIA's) forecasted oil price developments in three scenarios (Low, Reference and High) were used to predict the HFO and MGO prices. When it comes to LNG as bunker fuel, it is currently sold on long-term contracts at 7-8 USD/MMbtu in the Gulf and distribution costs of 2-6 USD/MMbtu come on top of this, leading to a possible long-term bunker contract price of 9-14 USD/MMbtu. In the financial analysis, we have used a reference price of 12 USD/MMbtu, a high price of 14 USD/MMbtu and a low price of 9 USD/MMbtu. All the prices have been adjusted based on inflation forecasts issued by the U.S. Bureau of Labour Statistics.



›› Figure 1: Triality cost structure compared to that of a conventional VLCC



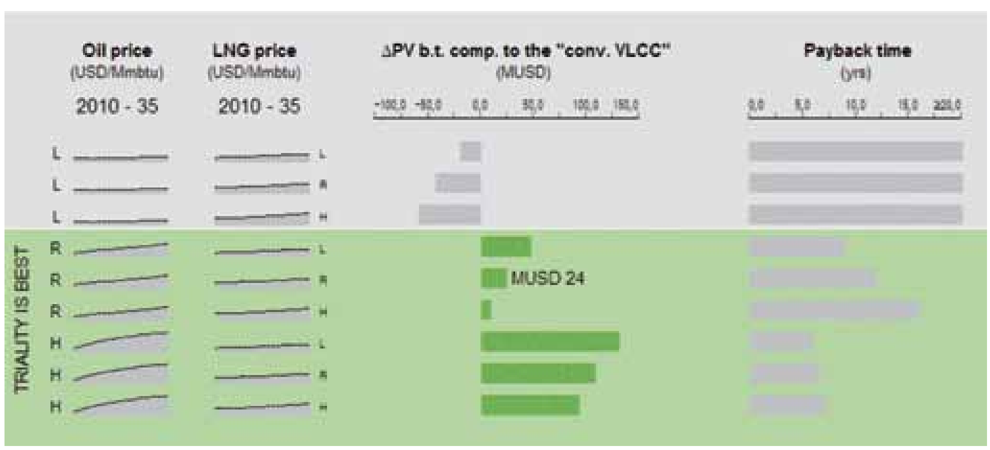
›› Figure 2: LNG break-even price for different price scenarios



›› Figure 4: Probability distribution between Triality and the conventional VLCC

CONVERSION FACTORS

- 1 MMbtu ≈ 21 kg LNG ≈ 25 kg MDO
- 1 ton LNG ≈ 1.17 ton MDO (energy)
- 15 USD/MMbtu ≈ 710 USD/ton LNG



›› Figure 3: Triality's financial performance given different fuel price scenarios

Are Triality solutions applicable to and attractive for smaller tankers?

The project has studied a VLCC size tanker. What about smaller tankers?

TEXT: **TORILL GRIMSTAD OSBERG,** TRIALITY PROJECT MANAGER, DNV

LNG FUEL

Suezmax, Aframax and smaller tankers can all benefit from using LNG as fuel to reduce their SOx, PM, NOx and CO_2 emissions to below existing and coming mandatory limits. The cargo deck normally has plenty of space available for LNG fuel tanks.

Dual-fuel slow-speed two-stroke engines were chosen for Triality. This is the preferred engine type for bigger vessels and those operating most of the time outside ECAs. It has high efficiency and is attractive from a maintenance point of view. For loads below 25%, these engines can currently operate on fuel oil only. When operating in ECAs, the more expensive Marine Gas Oil (MGO) may be needed to comply with SOx emission requirements.

The NOx reducing properties of medium-speed four-stroke gas or dual fuel engines are superior to those of the two-stroke gas/diesel engines. So, for tankers operating more of the time in ECAs, either pure gas engines or dual fuel low pressure engines may be a better choice, despite the fact that the installation may be more complex and include a reduction gear.

CONDENSATION OF CARGO VAPOURS – VOCS

The loss of cargo vapours (VOCs) is a challenge for all sizes of oil tankers. The benefits of using low temperature LNG to prevent this are assumed to be similar for different sizes of oil carriers.

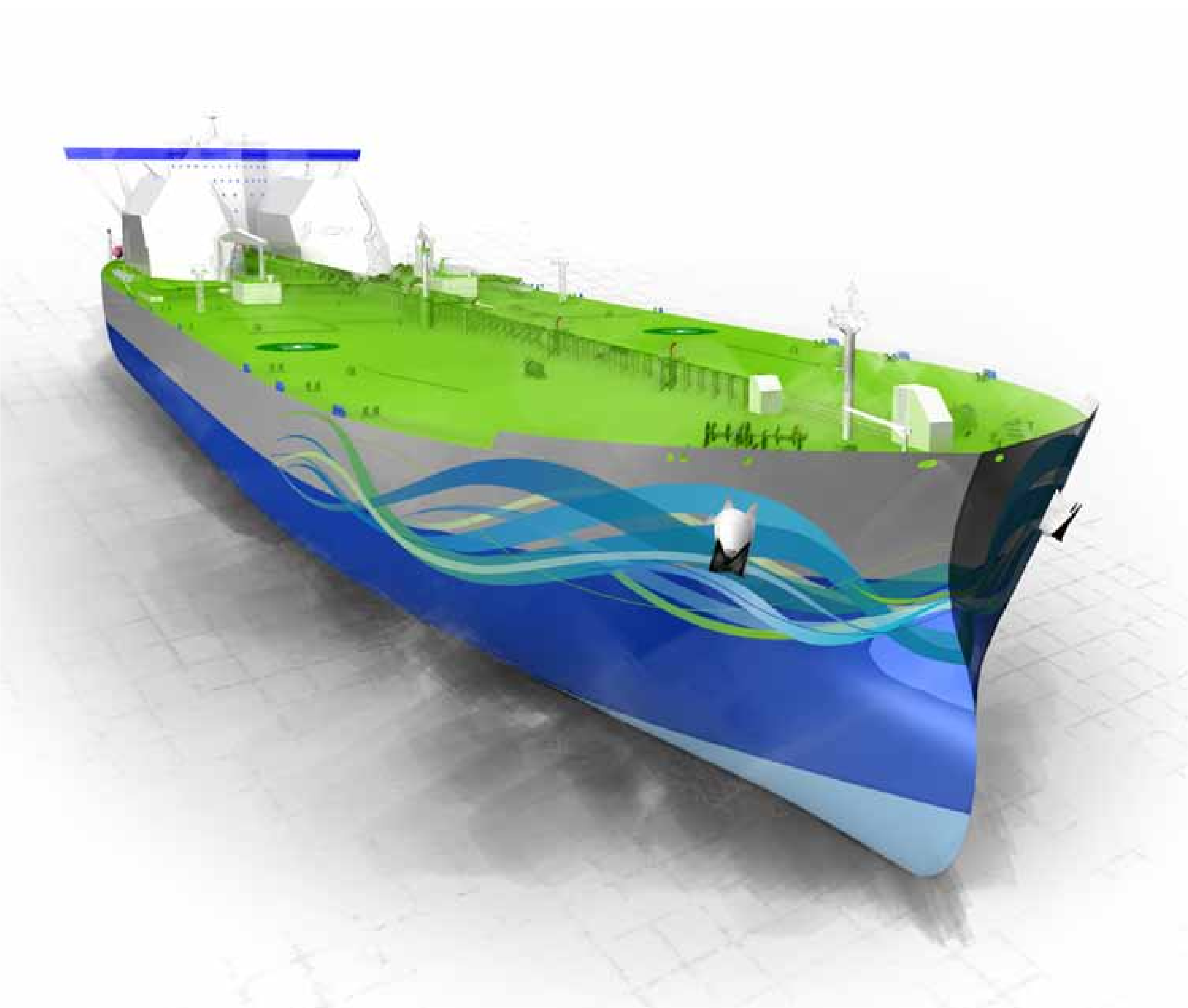
A BALLAST-FREE SHIP, INTERESTING FOR ALL SHIP SIZES

The requirement of a ballast water treatment system is a challenge for all the ship sizes concerned. There are significant investments involved in addition to the operational and maintenance costs and crew workload. Ballast-free ships, if possible, will therefore be attractive.

However, there are practical limits to how far down in size ballast-free oil tankers are feasible. Sufficient draft to avoid slamming problems and allow manoeuvrability must be included in evaluations for ballast-free smaller oil tankers. The possibility of reduced ballast volumes compared to present practice may also be of interest. This was beyond the scope of the Triality project. ○

Future delivery

VLCC TRIALITY



LNG FUELLED BALLAST FREE VLCC WITH VOC RECOVERY FEATURES

Particulars:

- LNG fuel capacity: 2 x 6750 m3
- Same maximum range as conventional VLCC's,: 25 000 nm
- Same loaded draft as conventional VLCC. 22.2 m
- Longer and wider than conventional VLCC:
- LPP: 352 m
- B: 70 m
- Block coefficient loaded: 0.60
- Block coefficient unloaded: 0.52
- Same cargo tank volume as conventional VLCC: 358 000 m3
- Service speed loaded: 15 knots
- Service speed unloaded: 16.6 knots
- Lightship weight: 50 600 tons
- Two slow speed dual fuel main engines
- Twin screw
- Low temperature LNG is used for
  - recovery of Volatile Organic Compounds (VOC)
  - cooling of scavenging air to engines
  - engine cooling
  - air conditioning
  - etc.