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**THE OPTIONS AND EVALUATION OF PROPULSION SYSTEMS FOR  
THE NEXT GENERATION OF LNG CARRIERS**

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## **Abstract**

The LNG shipping industry is going through a period of rapid change, with much larger size ships and novel propulsion systems being contemplated for the next generation of LNG carriers. This paper reviews the options currently available for the propulsion of the next generation of LNG carriers. It is written from the perspective of an Independent Oil Company (IOC) and is based on experiences gained in recent large-scale LNG projects. The paper examines the technology available and discusses the issues, highlighting such aspects as environmental emissions profiles, maintainability and reliability. The paper also discusses aspects of the methodology for carrying out economic assessment for the various options when evaluating proposals for a project.

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# PAPER

## 1 INTRODUCTION

All LNG ships in service, with the exception of two LNG/Ethylene/LPG vessels of about 30 000 m<sup>3</sup> capacity, have been driven by steam turbine propulsion systems. The first generation of LNG ships built in the 1960's employed steam turbine plants and, in doing so, established the technical concept for burning boil-off gas in boilers, which is still applied today. Whilst the steam turbine systems have proved extremely reliable, compared to alternatives, they are inefficient in terms of fuel consumption. It should be noted that the oil price shocks of the 1970's brought about the demise of steam turbines in virtually all other merchant marine applications. The fuel consumption of steam ships compared to diesel engines was just too high to bear in non-LNG ship applications. This has led to a situation of fewer manufacturers, less experience in the marine industry and concerns about maintenance of the specialized skill-pool.

For LNG ships built up to about 20 years ago, there was little incentive to seek more efficient propulsion plants because the state of the cargo tank insulation technology was such that, on a laden voyage, the natural boil-off gas flow provided approximately 100 % of the fuel requirements - i.e. even if more efficient plants were available, they could not be used without wasting boil-off gas. However, developments in insulation have resulted in significantly lower boil-off rates such that the advantages of more efficient propulsion machinery can be realised.

Over the years, Shell Shipping Technology has studied various propulsion options for LNG vessels. For an alternative to be attractive, it must obviously be economically 'better' than the traditional steam turbine option whilst delivering similar high levels of reliability, redundancy and maintainability.

## 2 BASE CASE - STEAM TURBINE PLANT

The steam turbine represents the 'base case' since all but two LNG ships in service employ this type of propulsion plant. The plant, in outline, consists of two boilers supplying steam to a cross-compounded double reduction geared steam turbine plant driving a single propeller. Steam is also supplied to auxiliary services, the main one being the turbo generators which provide the electrical power. The capacity of the turbo generators is dictated by the electrical load required during discharge using the electric cargo pumps. Two turbo generators are sized to meet the discharge port load, one of which fully satisfies any load at sea. Two auxiliary diesel engines are installed, the combined capacity being equal to one turbo generator.

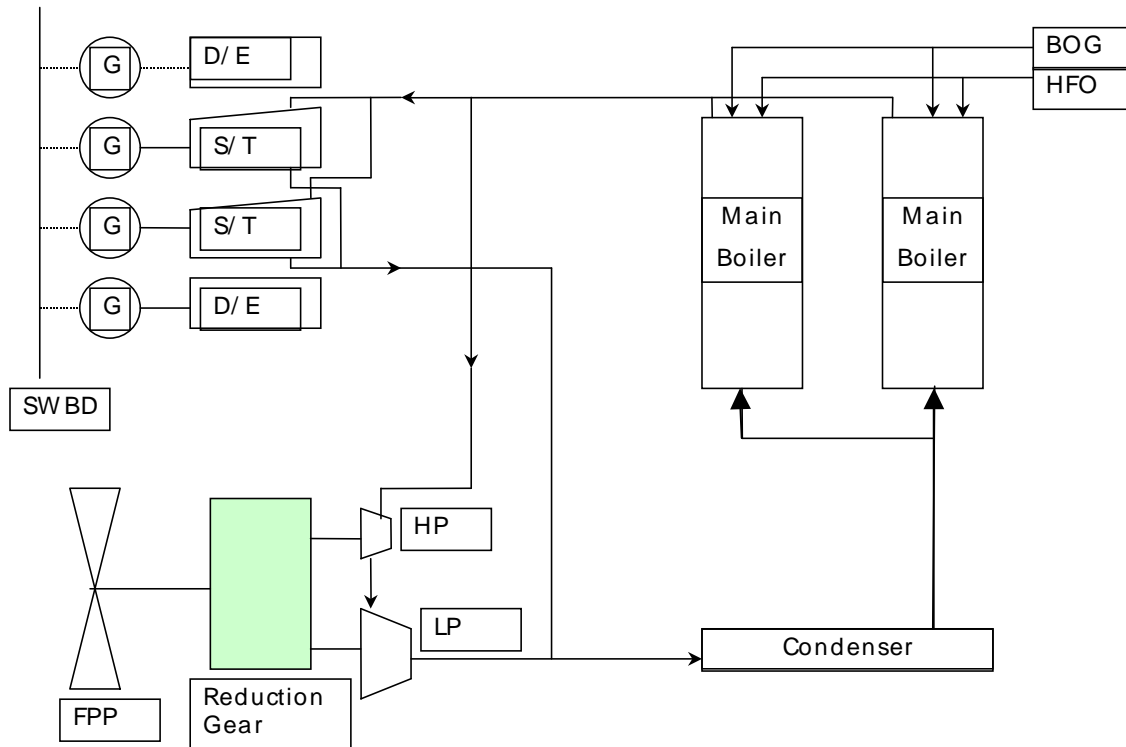
Most LNG ships in service have 1 x 100 % capacity auxiliary diesel, Shell Shipping Technology has led the way to install 2 x 50 % on newbuilds to give increased protection against a single point failure leading to difficulty in recovering the plant after a black-out.

With the exception of the auxiliary diesel generator arrangement, the concept of the modern LNG ship steam turbine plant is practically identical to that of the first LNG ships to enter service in 1964.

In the case of larger LNG ships, 200 000 m<sup>3</sup> and above, a situation is arising where the installed propulsion power requirement is above current service experience, the largest turbine plants in merchant ship service are about 30 – 33 MW. The limiting factor is gearing torque capacity. Whilst twin skeg designs have been proposed for LNG ships, the physical constraints of the steam turbine prevent their installation on these designs.

A further disadvantage of steam turbines may arise if ice navigation is considered. Typically, steam plants are designed to give a maximum of about 40% astern power, whereas the diesel driven options can give approaching 100% astern power.

## Steam Turbine Propulsion



This paper considers the following propulsion systems as alternative to the steam turbine systems:

- Slow Speed Diesel with reliquefaction (DRL)
- Dual Fuel Diesel Electric (medium speed diesels) (DFDE)
- Gas Turbine Electric GTE
- High Pressure Gas Injection Slow Speed Diesel (DFD)

### 2.1 Twin Screw Issue

It is generally recognised that the next generation of larger LNG ships will employ twin-screw propulsion systems. The drivers for this change from the traditional single screw system are various but include such factors as propeller induced vibrations, redundancy and maintainability.

The larger LNG ships currently being designed and built are relatively shallow draft for the propulsion power needed. To try to execute a suitable design with a single screw may not be achievable since the propeller loading may be too high. This leads to adverse effects such as cavitation and high vibration levels induced into the hull structure.

The reliability of steam turbine single screw LNG ships is accepted throughout the industry. It is also noted that they require little regular routine maintenance, which can only be conducted with the propulsion system immobilised. By contrast, slow speed diesel machinery needs regular immobilisation for maintenance. Normal industry practice is not to permit complete immobilisation of propulsion machinery whilst an LNG vessel is alongside. With a twin-screw ship, immobilisation of one diesel engine, providing the vessel can sail on the other, may be considered acceptable.

There is no clear-cut break point beyond which single screw is not acceptable, but the decision to utilise twin-screws is also a function of the choice of propulsion machinery and the amount of power

to be delivered. In practice, whilst satisfactory twin-screw designs at the current standard LNG ship design of about 140 000 m<sup>3</sup> can be produced, the current view is that they will become industry standard for ships greater than about 200 000 m<sup>3</sup>.

### **2.1.1 Concept Approval**

Within Shell Shipping Technology we have a formal review process for acceptance of novel technologies or concepts for use in projects. Studies are undertaken to assess the new technologies and, particularly, to identify potential risks and mitigation measures for those risks. The studies do not particularly address economical aspects, although one has to recognise that the main driver for new technology is generally an economic one.

The studies result in a report called a 'Technical Release' which goes through a formal review process with senior management before final issue. Of the alternative propulsion systems considered here, dual fuel diesel electric, gas turbine electric, slow speed diesel with reliquefaction and high pressure injection slow speed diesel, all apart from the latter have a Technical Release. The Technical Release for high pressure injection diesel engine is work in-hand.

## **2.2 Slow Speed Diesel with Reliquefaction**

This option employs conventional low speed diesel engine technology for propulsion purposes and a reliquefaction plant to turn the boil-off gas back to liquid and return to the cargo tanks. At a conceptual level, this is similar to the practice for fully refrigerated LPG vessels. Various designs for LNG reliquefaction plant have been proposed, all of which work on a nitrogen cycle based on the 'Brayton' principle whereas LPG ships usually employ either direct refrigeration plants with reciprocating compressors or indirect refrigeration plants using a common refrigerant, e.g. R407c, in the primary cycle. For current sized LNG vessels, this implies an additional electrical load of 3 to 4 MW although for the largest vessels contemplated, around 250 000 m<sup>3</sup> capacity, the plant load rises to about 5 MW.

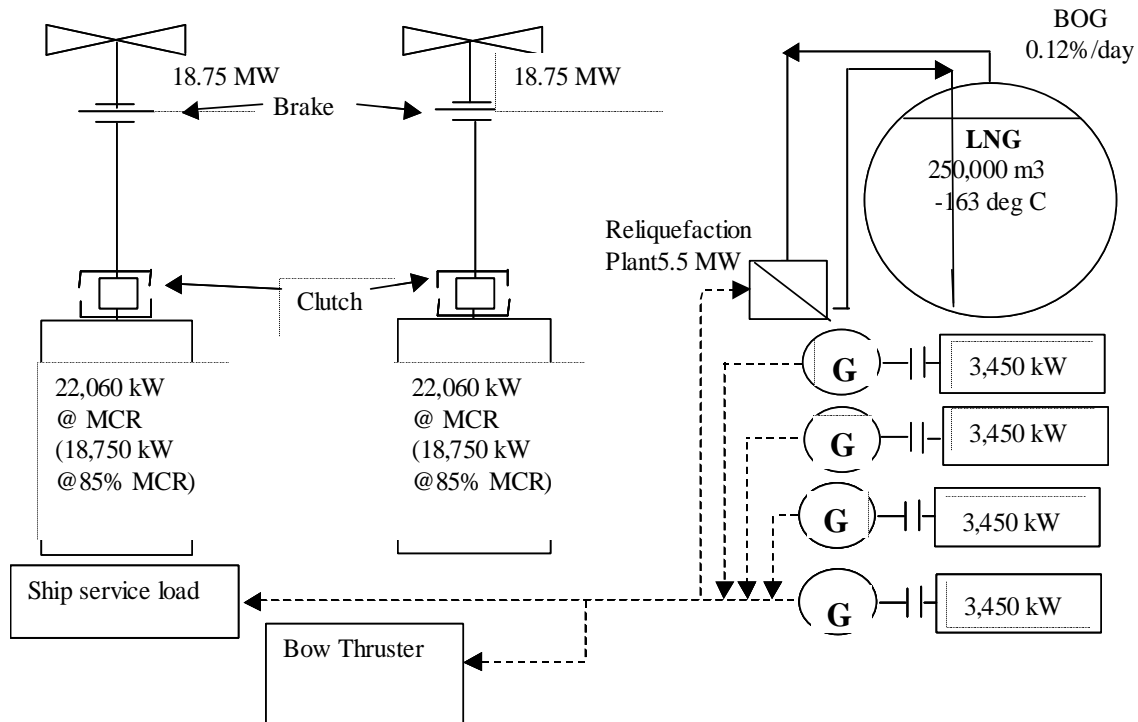
We foresee the main application of this technology on the larger LNG vessels in a twin-screw format. In this format, we believe that the installation of clutches and shaft brakes in each shaft line are essential to achieve expected availability and maintainability requirements.

From a plant concept point of view, one of the key issues is the integration of the reliquefaction plant power requirements into the normal ship generating systems. During our studies we investigated the use of shaft driven generating systems. These tend to be popular with ship operators since they greatly reduce the running hours, and hence maintenance burden, of the auxiliary diesel generator engines. However, we could not satisfy ourselves that a technically viable solution for a twin-screw ship could be materialized and hence the generating plant is based on a commonly applied approach on merchant ships of using four auxiliary generator engines, any three of which together can supply the normal full ship's load. Clearly, the capacity of each of these engines is significantly higher than commonly found on current LNG ships as a result of the reliquefaction plant load.

Whilst there are still some unknowns around the operation and maintenance of the reliquefaction plant, simply because there is, as yet, no body of experience with these plants onboard ships, our review of studies by manufacturers lead us to expect high availability and undemanding maintenance in service. We concluded, based on availability studies, that we would install a single 100 % capacity reliquefaction plant plus a 100 % capacity gas incineration system for when the reliquefaction plant is not available. The only part of the system to be duplicated is the boil-off gas compressors because these are used both to feed the reliquefaction plant and the incinerator.

The main issues with this plant concept remain the relatively poor emissions profile (see Section 3) and high maintenance requirements for the diesel machinery.

## Diesel Reliquefaction System configuration



### 2.3 Gas Turbine Electric

Over the years, we have kept a watching brief on gas turbines and note their increasing application at high powers. There has been, and continues to be, much research on gas turbines with significant improvements on thermal efficiency and reliability.

Today, the thermal efficiency of a simple cycle gas turbine is around 40 % and is starting to show a real advantage compared to a steam turbine, and the installation costs should be lower. The efficiency can be improved to that of a modern diesel by inclusion of extensive waste heat recovery systems – i.e. combined cycle systems, however this increases the CAPEX and complexity of the plant.

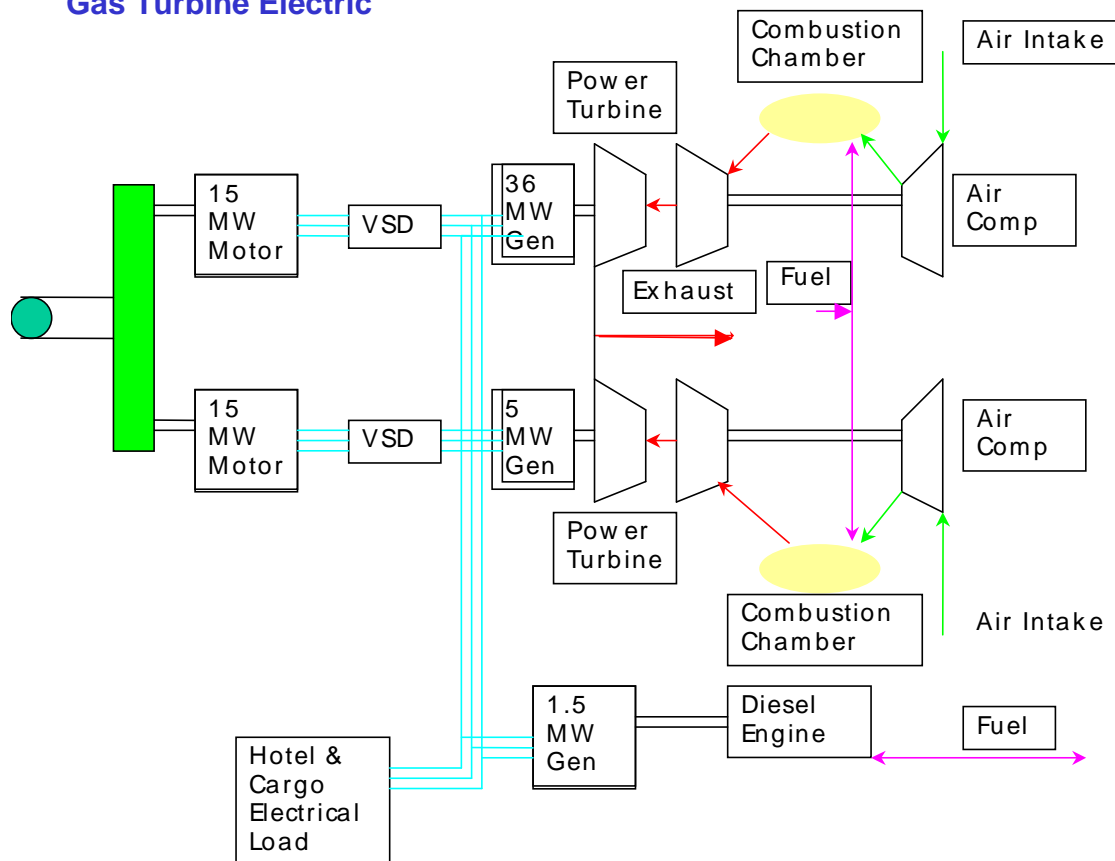
We have studied the application of gas turbines to LNG ships. There are several concepts that could be applied, but the one we focused on is that of a simple system based on two gas turbines (in a father-son arrangement) with an electric propulsion system. The gas turbine generator sets would be provided in sound-proof enclosures and positioned relatively high up in the ship, say at aft sunken deck level, to facilitate removal for maintenance.

A key feature of this proposal, as for the DFDE, is that the system is designed on the basis of using gas (boil-off gas plus vaporized LNG) as the primary fuel source. Key advantages of this are that from the aspect of environmental emissions, fuel gas gives the lowest emissions profile.

One distinguishing factor with gas turbine primary power generation is that the maintenance of the gas turbines, other than a low level of operator maintenance is done by replacement with a spare unit. The practical maintenance burden is therefore taken off the ship.

Further details can be found in Ref 1<sup>1</sup>.

## Gas Turbine Electric



## 2.4 Dual Fuel Medium Speed Diesel Electric

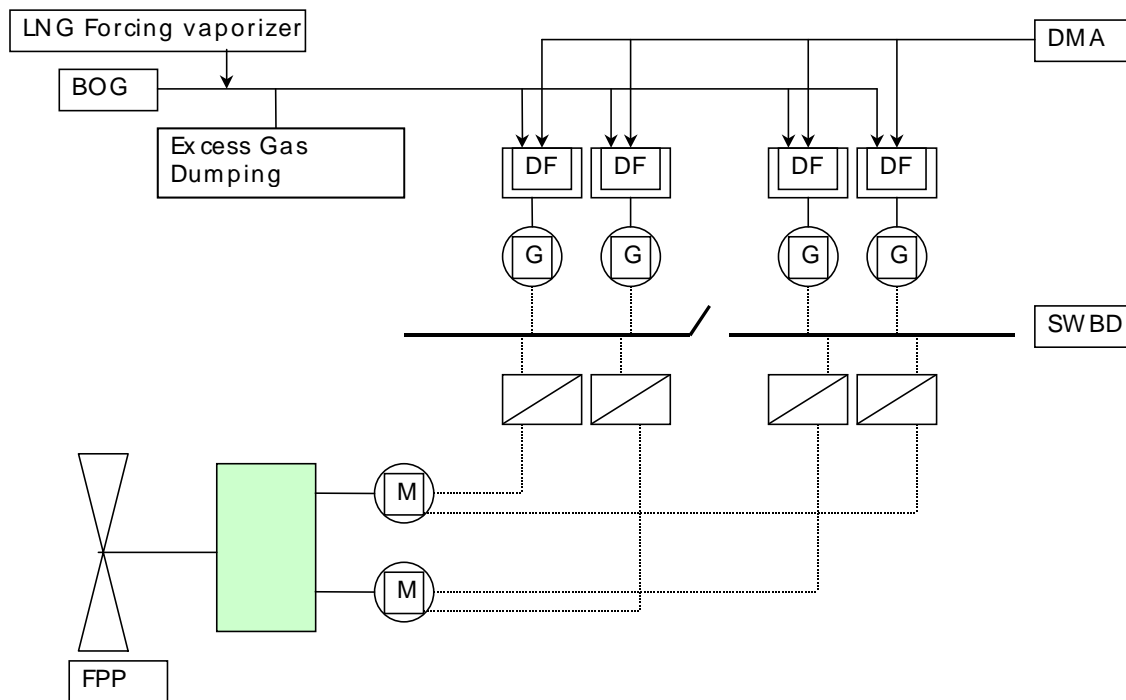
This concept employs multiple dual fuel diesel generators, typically four, to provide all the vessel's power requirements, including main propulsion, on a 'power station' principle. The concept is comparable to that commonly found on modern cruise liners, the main difference being the fuel for the diesel generator engines.

Burning methane in a diesel engine presents technical challenges. The main problem is that of controlling the detonation characteristics ('knocking') of methane in an engine cylinder. The development of DFD engines has been the subject of Research and Development programmes for many years. This work has finally led to a technically feasible engine using low pressure gas injection developed by Wärtsilä and designated 'DF'. The first 'DF' engine entered service in a shore plant about 7 years ago and, at the time of writing, there were 18 LNG ships with these engines on order/under construction. Of the alternatives to steam turbine technology discussed, this is the nearest to operation.

The gas is injected in a carefully controlled manner before each inlet valve on the induction stroke. To ensure reliable ignition, pilot fuel injection of DMA<sup>ii</sup> is used, supplied via a separate 'common rail' system. Wärtsilä has developed a very sophisticated control system to control, within tight limits, the combustion process. In automotive terms, the engine is operating in a 'lean burn' mode when running on gas. By these means, the engine can be operated successfully at a high rating without detonation.



## Electric Propulsion with 'DF' Engines



The DF engine either operates on gas with pilot fuel injection, or on liquid fuel. Variable mixtures of fuel and gas cannot be used in this engine although, which is a disadvantage when compared to the basic steam plant which can do so. When operating on liquid fuel, the engines may run on heavy fuel oil (HFO) on a continuous basis. Before returning to gas operation a short period of running under load on DMA is required to eliminate the risk of glowing residues from the HFO being left in the cylinder. Such residues would lead to the premature ignition of the gas fuel.

To comply with IGC Code <sup>iii</sup> requirements necessitates a means of managing boil-off gas when the ship is not under way. This requirement is satisfied by a thermal oxidizer or incinerator. This is designed to incinerate boil-off gas at a rate equivalent to the normal laden boil-off rate.

The provision of multiple independent diesel generator sets provides a strong guarantee against total loss of propulsion power in event of plant upset. The most likely consequence of an unscheduled engine shut down is a relatively small loss of speed. It is considered that this concept meets all requirements for reliability, redundancy and maintainability.

### 2.5 High Pressure Injection Diesel

The difficulties associated with burning gas in diesel engines have been noted above. A different solution to low pressure injection is to inject the gas at high pressure at the end of the compression stroke in a similar manner to that for liquid fuel. Pilot injection of liquid fuel is necessary to give reliable combustion. Much work was done on this in the 1980's culminating in a full sized low speed diesel being built by Mitsui Engineering and Shipbuilding at Chiba. The demonstrator performed satisfactorily from the technical point of view but the Achilles' heel of the design is that the fuel gas has to be compressed to a high pressure, of the order of 250 bar, before it can be injected. The energy required for compression reduces the efficiency gains of going to a diesel engine propulsion

system. The technology is already applied in special applications where high pressure gas is available, e.g. from re-injection compressors on offshore facilities.

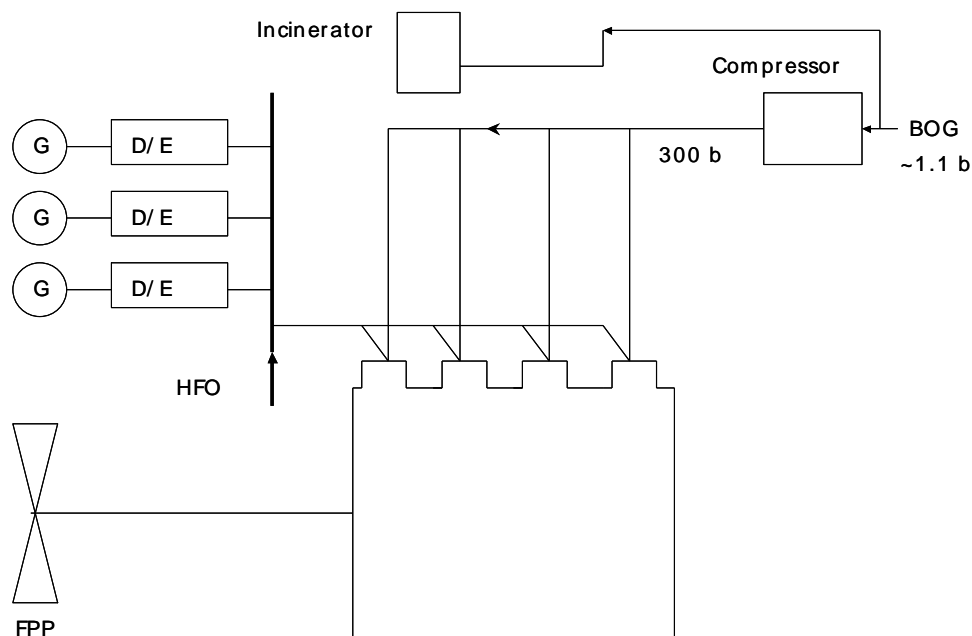
From the point of view of application to ships, the main issues are around the high pressure compressor system and its control.

This option offers similar levels of flexibility with respect to fuel choice as the steam turbine ships, with the advantage of an overall improvement in thermal efficiency.

For periods when the main engine is not in use, e.g. when the vessel is at anchor, a 100 % capacity gas incinerator will be installed to ensure compliance with this IGC code.

This technology is currently under study by Shell Shipping Technology with a view to issuing a 'Technical Release'.

### Duel Fuel Diesel DRL



### 3 EMISSIONS

There is increasing interest at all levels of society into harmful emissions to the atmosphere. This section compares the emissions from the various propulsion system options.

The following table summarises the harmful emissions to air for various types of propulsion system. These figures are derived from various sources and are indicative only, since such factors as fuel composition and quality of maintenance can affect the values. The figures for the 2-stroke and 4-stroke diesel engines are based on engines consuming a heavy fuel oil, such as RMH 35 with a typical sulphur content of about 3.5 %. The dual fuel diesel electric is burning gas with a 1% pilot injection of light diesel such as DMA and the slow speed DFD is assumed to be burning gas with 1 % HFO pilot fuel injection. The steam turbine option is based on dual firing the boilers with 50 % of the energy input coming from HFO and 50 % from boil-off gas. The gas turbine is open cycle configuration and the fuel is 100 % gas, based on standard fuel combustors, even though 'low NOx' combustors are available.

**Table 1 Emissions from Marine Prime Movers**

	<b>NOx (g/kWh)</b>	<b>SOx (g/kWh)</b>	<b>CO<sub>2</sub> (g/kWh × 100)</b>	<b>Particulates (g/kWh)</b>
2 Stroke Diesel (Low Speed)	17	12.9	5.8	0.5
4 Stroke Diesel (Medium Speed)	12	13.6	6.12	0.4
Dual Fuel Diesel Electric	1.3	0.05	4.2	0.05
Dual Fuel Diesel (Slow Speed)	14.5	0.2	4.1	0.1
Steam Turbine	1	11.0	8.5	2.5
Gas Turbine	2.5	0	4.8	0.01

### 3.1.1 Sulphur Oxides

Emissions of Sulphur Oxides (SOx) are purely a function of the sulphur content of the fuel and the amount of fuel consumed. The figures in the table are based on a typical fuel oil with 3.5 % sulphur content. The primary fuel for the DRL option is HFO, hence the emissions level for this concept is significantly worse than the alternatives.

For the gas turbine based propulsion systems, where the primary fuel is gas, the emissions of SOx compounds are zero in normal operations. For the short periods in service when gas is not available, i.e. for voyages to and from refit, the vessel will use light diesel fuel of DMA quality. These, compared to HFO, have a low sulphur content.

For the DFDE, the SOx emissions are derived purely from the sulphur content of the pilot injection fuel and hence are very low compared with DRL burning HFO and steam turbine plants burning a mixture of HFO and boil-off gas.

As for DFDE, the high pressure injection DFD engine SOx emissions are purely a function of how much pilot HFO is consumed.

There are increasing pressures in the marine industry to reduce or eliminate SOx emissions. IMO MARPOL Annex 6 has recently been implemented and puts a global sulphur cap of 4.5 % on all fuels from 19<sup>th</sup> May 2005 and introduces Sulphur Emissions Control Areas (SECA) for the Baltic Sea (19<sup>th</sup> May 2006), the North Sea and the English Channel (1<sup>st</sup> Feb. 2007) where limits will be imposed of 1.5 % sulphur in HFO for ships at sea. The concept of SECA's is likely to spread and one could foresee their introduction, say, throughout the Mediterranean Sea or on the East and West coasts of USA.

The EU is developing regulations in this area and is currently proposing 0.1 % mol. weight of sulphur in all fuels consumed in port areas to be mandatory from 2010. This implies, for ordinary vessels, use of low sulphur HFO's or, probably more practically, diesel oils of the DMA type quality for all purposes in port.

The DRL option has no practical optionality for fuel choice, it cannot burn boil-off gas in the engines, therefore, considering the potential 40 year life of these vessels, this aspect represents a significant uncertainty about the long-term economics concerning the supply of the fuel for these engines. For the other alternative propulsion systems discussed in Section 3 of this report, they may operate with the primary fuel source as gas, with no sulphur content; and they also have the technical option of burning gas in port (subject to the terms of Sales and Purchase agreements).

Whilst most of the effort has been about reducing the sulphur content of fuels in the first instance, alternative technical solutions, such as scrubbing of the exhaust gases to remove SOx compounds, are considered feasible. However, there are issues relating to the treatment of the effluent scrub water and the space needed for the installation.

Whereas there is established methodology to put a value on CO<sub>2</sub> emissions, there is currently no equivalent for SO<sub>x</sub>.

### **3.1.2 Nitrogen Oxides**

NO<sub>x</sub> emissions are a function of the combustion process. The key factors are the peak temperature achieved and the duration that the gases are at this peak temperature.

Slow speed diesel engines, as used in the diesel with reliquefaction option, are the worst offenders as far as emitting NO<sub>x</sub>. The DFDE engine, however, is really operating as a gas engine and, as such, is inherently a low NO<sub>x</sub> engine, particularly when compared with engines running on HFO. IMO MARPOL Annex 6 limits the NO<sub>x</sub> emissions, based on the engine type. For slow speed diesels, the limit is 17 g/kWh and modern diesel engines will need careful maintenance to stay within these limits.

For the high pressure injection DFD engine, earlier work indicated a reduction of about 15 % for the NO<sub>x</sub> emissions compared to a conventional HFO-burning slow speed diesel engine.

For the gas turbine option, even with standard combustors, NO<sub>x</sub> emissions are low compared to diesel engine technology. Should even lower levels be required, then technology exists in the form of 'dry, low-NO<sub>x</sub>' combustors ('DLN') for the gas turbines.

NO<sub>x</sub> can be removed from the exhaust gas by selective catalytic reaction. The reaction needs high exhaust temperatures to be effective and hence the reactor vessel is placed between the engine exhaust collector and the turbocharger inlet. A continuous supply of urea reagent is needed and the catalyst life is limited to an estimated 20 000 h.

As for SO<sub>x</sub>, there is no current methodology for putting a value on NO<sub>x</sub> emissions.

### **3.1.3 Carbon Dioxide**

Carbon Dioxide (CO<sub>2</sub>) emissions are primarily a function of the quantity of fuel burnt, but is also a function of the composition of the fuel being burnt. From this, it is clear that the efficiency of the plant has a major impact on the quantity of CO<sub>2</sub> emissions, and this is demonstrated in Table 6 below, which shows the steam turbine as worst in this respect. The next worst is the DRL option, this arises because of two effects; there is a high primary power requirement as a result of the power needed for the reliquefaction plant, and the carbon to hydrogen ratio favors gas as a fuel over HFO. The open cycle gas turbine option is better than the diesel with reliquefaction option and almost as good as the dual fuel diesel. All internal combustion options are significantly better than the steam plant.

### **3.1.4 Particulate Matter**

Particulate matter emitted from combustion processes has become a serious health concern in many countries. This applies especially to particulate matter below the size of 10 microns (PM10). Diesel engines are a main source of these particulates. Diesel engines burning low quality fuel emit significantly more particulate matter than those burning clean fuels, such as gas.

The dual fuel diesel emits few particulates compared with diesel engines running on HFO. In operation, the particulate emissions for steam turbine are a function of how much HFO is burnt and peaks during 'soot-blowing' operations. However, the particles generated are considered sufficiently large (i.e. larger than PM10) to not present a health hazard.

Gas turbines burning gas emit virtually no particulates.

There is currently no methodology for putting a value on particulates.

### **3.1.5 Carbon Costs**

Unlike the case for SO<sub>x</sub> and NO<sub>x</sub>, there is an established methodology for valuing CO<sub>2</sub> emissions based on the 'Kyoto Protocol'. (The Kyoto Protocol specifically excluded shipping and international aviation however many countries to which LNG ships may trade have ratified the UN Framework Convention on Climate Change and, for instance, all EU members are so-called 'Annex 1' countries

with legally binding emission limits in the Protocol's first reduction period. It should also be noted that IMO have been invited to address this issue for international shipping) The indicative carbon cost for Annex 1 countries is USD 5.5 /t CO<sub>2</sub>e, however it is noted that in carbon trading within Europe, values of the order of USD 20/t CO<sub>2</sub>e and higher are being realized. The value to use is really a project decision and is outside the scope of this paper. Table 2 below gives indicative annual amount of emissions for alternative propulsion options for a large LNG vessel with a propulsive power of 37.5 MW.

All the propulsion systems for LNG ships burn the natural BOG, except for the DRL option. In this case, the BOG is re-liquefied and returned to the cargo tanks, however, as part of this reliquefaction process, there is a need to vent non-condensables from the reliquefaction plant. The main component vented is nitrogen, but it also entrains methane, which is lost to atmosphere.

The following simplified calculation attempts to quantify the environmental impact of this loss. It is an order-of-magnitude type calculation based on a worst-case situation.

Most commercial grades of LNG have a nitrogen content of 0.1 to 0.4 mol %, however the commercial limit is taken as 1.0 mol %. A full cargo of 220 m<sup>3</sup> of LNG may therefore contain about 1000 t of N<sub>2</sub>. Assuming 80 % of this is lost through boil-off, and rejected to atmosphere, then, according to manufacturer's data, 160 t of CH<sub>4</sub> will also be lost per voyage. Assuming a 46.8 day round voyage (based on Arabian Gulf to Gulf of Mexico, and 353 days available per year, this implies a worst-case loss of 1200 t of CH<sub>4</sub> per year. Methane emissions, on a mass basis, have 21 times the impact of CO<sub>2</sub> on the environment, hence this 1200 t of CH<sub>4</sub> can be equated to 25 000 t CO<sub>2</sub>e. This figure is included in the table below for the DRL option.

The base assumption in the above calculation is that the non-condensables from the reliquefaction process are vented to atmosphere. It is technically possible to route the vent to an incinerator, however, the mixture of nitrogen and methane in the non-condensables is barely flammable, hence to achieve effective and reliable incineration there would be a need for additional fuel input

The CO<sub>2</sub>e in the following table is derived from the power requirements and the figures in the table above.

**Table 2 Estimates of Annual CO<sub>2</sub> Emissions**

<b>Propulsion System</b>	<b>CO<sub>2</sub> + CH<sub>4</sub> (tonnes/annum CO<sub>2</sub>e)</b>	<b>Total CO<sub>2</sub>e /annum (tonnes)</b>
Steam Turbine	250 000	250 000
Diesel with reliquefaction	190 000 + 25 000	215 000
Dual Fuel Diesel electric	130 000	130 000
Dual Fuel Diesel (slow speed)	120 000	120 000
Gas Turbine	150 000	150 000

#### **4 ITB PACKAGE**

Whilst Shell Shipping Technology's Technical Release process defines the technical acceptability of various options, the final decision is typically only determined after a bidding process with shipyards so that economics can be based on real CAPEX figures etc. and the best possible estimate of OPEX.

The bidding process is conducted under strict rules under the oversight of a Tender Board. This is essential to ensure transparency of the process and thus avoid charges of malfeasance. The objective of the bid process is to achieve the best possible contractual terms and conditions on a technical acceptable bid.

A key element of this process is developing an 'Invitation to Bid' (ITB) package to go out to selected shipyards. This consists of three principal elements:

Instructions to Bidders  
Performance Specification  
Pro-Forma Shipbuilding Contract

#### **4.1.1 Instructions to Bidders**

The purpose of this is self-evident and includes such information as a general description and timing of the bidding and evaluation process. Shell Shipping Technology's preferred process is a two round bidding system. The first round embraces as wide a selection of shipyards as can reasonably be expected to provide a realistic bid, both in technical and commercial terms. From this, a short-list of shipyards is selected for very detailed evaluation to lead to a second bid and contract.

#### **4.1.2 Performance Specification**

This sets out the main technical parameters for the ship and may include various options. For a novel technical option to be included, it must have been approved internally by way of a 'Technical Release'. The main parameters, ships capacity, speed and number, and any dimensional limitation (e.g. draught or air draught) are determined from fleet definition studies which are an iterative process involving the business development groups since it is heavily dependent on the mix of ports to be visited. For a specific project it may result in a fleet of different sized vessels. Whilst our philosophy is to encourage shipyards to be innovative in their design approach, there are some areas where we tend to be prescriptive in the Performance Specification. These areas are those where, from our operating experience, we are prepared to specify higher standards than shipyards may typically offer. One such area, for instance, covers all aspects relating to corrosion prevention of the hull structure.

The response to the ITB from a shipyard is typically a package containing a commercial bid a full shipbuilding specification. There may also be comments on the pro-forma shipbuilding contract.

## **4.2 Evaluation**

As noted above, the outcome from the first round is a short list of yards for second round bidding. A technical review is conducted of all the bids, but the main criteria for going into the second round is CAPEX, including the effects of stage payments, financing etc. Assuming that there have been no major deviations or misinterpretations of the performance specification, a bid which is, say, 5 % above the best in a competitive first round tender is unlikely to lead to the best final deal, no matter how good one's own negotiators are. Such a bid will not be included in the second round. This may sound tough, but it is clearly spelled out in the Instructions to Bidders.

The key objective of the second round of the evaluation is to ensure that the comparison between short-list offers is equivalent on all technical, contractual and commercial terms such that the final decision can be based on economic indicators. The economic indicator used is the unit freight rate expressed as USD/mmBtu for the voyages used in the original project definition studies. The concept is that all costs related to that round voyage, including financing the CAPEX and all OPEX are divided by the number of Btu's delivered.

Much care is needed in compiling the 'cost' side of the formula. The costs associated with CAPEX are fairly easy to determine. These include contract price, effects of stage payments and costs associated with financing and supervision. For OPEX, there are a number of key issues. The biggest one of these is the value ascribed to BOG and to vaporized LNG if used as fuel for the vessel. Through life maintenance costs can also be a bit difficult to determine. Nevertheless, the point to remember is that this is a comparative exercise to aid decision-making. Therefore, absolute accuracy is not so important; effort should be spent though on trying to quantify in monetary terms on a consistent basis affects which arise because of differences in design or technology.

Another very useful aspect of this approach is that environmental costs can easily be included, providing there is some basis for the establishment of those costs. For instance, the CO<sub>2</sub> emissions

in exhaust gas can be estimated on a time base and the effects costed using an appropriate USD/t figure.

The limitation of this process is that there may be 'soft' issues which can not be given a dollar value, and hence cannot be included in the final evaluation. With such issues, the best we can do is to carefully study and ensure the business unit responsible for the project is aware of the issues.

## 5 CONCLUSIONS

This paper describes at a conceptual level four alternatives for propulsion concepts to the traditional steam turbine system. Of these four, three have been through formal 'Technical Release' process in Shell Shipping Technology. For the fourth one, high-pressure injection diesel engine, the process is in hand.

These options give a range of technically feasible solutions for LNG project shipping and the challenge in the evaluation process is to bring all the differing features into a system where a transparent comparison can be made on an equivalent basis.

There is no one best solution for all projects, rather the range of options allows, together with a rigorous evaluation procedure, that the best solution for a particular project to be selected.

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<sup>i</sup> "A Natural Evolution of the Modern LNG Carrier – The Application of Gas Turbines for LNG Carrier Propulsion Systems" GASTECH 2005

<sup>ii</sup> "ISO 8217 Standard; 1996 International Standards for Marine Distillate Fuels" – sometimes referred to as Marine Gas Oil.

<sup>iii</sup> "International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk" or "IGC Code"