Iguana Seacraft Ltd

UK LNG Fast Ferry Program and Challenges

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Contents

INTRODUCTION

The global trend in de-Carbonisation of the energy system replicates the path:

COAL > OIL> NATURAL GAS > HYDROGEN

The drive towards environmentally friendlier fuels points next [0] at Natural Gas (NG) and the infrastructures to support that trend are being pre-positioned by corporate mechanisms and governmental bodies worlwide[1]. NG is to be cheap and plentiful.

Natural Gas as fuel is well established in the Urban Transport and Power Generation sectors and that technology will transfer sympathetically to the marine industry via availability of engines, systems and technical assistance.
Internationally its operational record is rated as GOOD and in the US the cost of NG is presently competitive with ship's Diesel.
A ferry operation requires fuel supplied in bulk rendering the NG distribution viable.

The use of an alternative fuel for vessel propulsion leads to a design review of powerplant, associated fuel system and propulsion train; effectively reshaping areas such as Machinery Arrangement, Hull Form, Compartmentation, Car Deck, Payloads, Superstructure, Interior Layouts, Escape & Safety, Route Options, etc.

A rapid estuarial Ro-Ro commuter ferry design is herein proposed aiming at new opportunities and openings for estuarial ferry operations using Natural Gas fuel.

1.1 NATURAL GAS (NG) as a Marine Fuel

In 1997 [2], the IMO adopted the new Annex VI to the MARPOL Convention concerning harmful emissions of nitrogen oxides, NOx, and oxides of sulphur, SOx, from shipboard machinery to air, as stated in Regulation 13.

Thus, since January 1, 2000, all incinerators and diesel engines over 130kW (174hp) fitted on ships and offshore installations will have to comply with the new emission controls, regardless of when the annex comes into force.

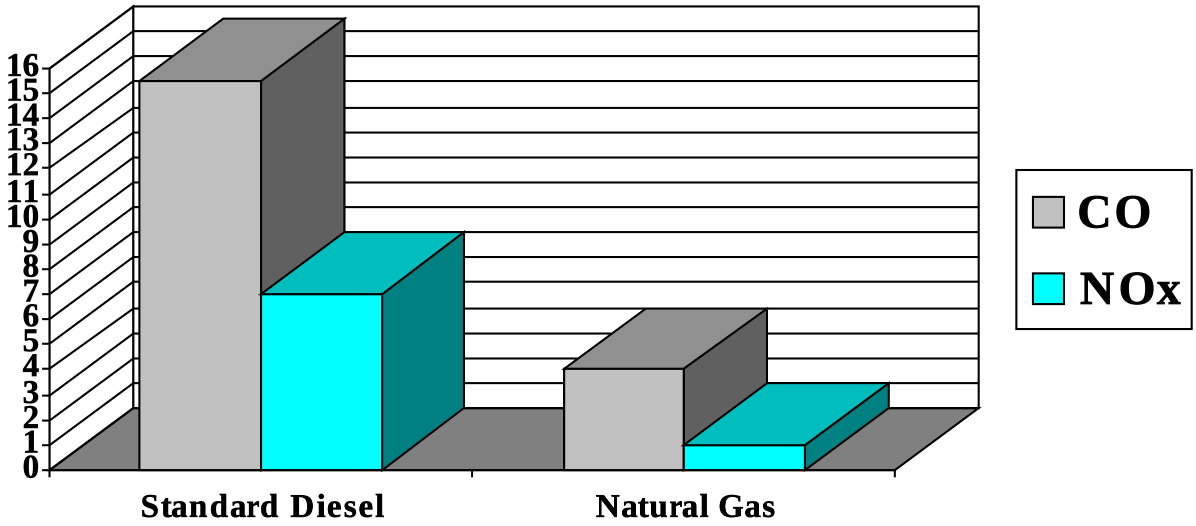
Over all the marine industry is coming in line with many other oil fuel users in adopting exhaust emission controls. It is though expected that these requirements represent the first stage in regulation with imposing ever wider and tighter controls on marine exhaust emissions, at a global level.
In addition to the NOx and SOx restrictions there will be increasing pressure on marine engines regarding reduction of carbon monoxide (CO), hydrocarbons (HC) and particulates (PM) or smoke, with machinery energy efficiency rated in terms of carbon dioxide (CO_2) emissions.

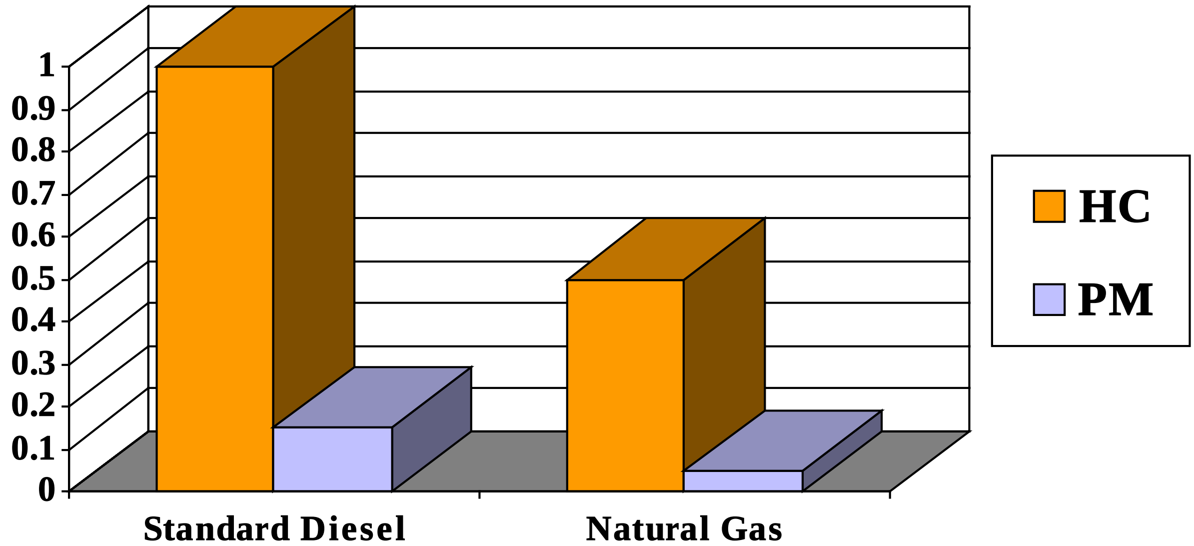
Compared with Diesel, Natural Gas fuel produces remarkably lower emissions overcoming the IMO's Annex VI requirements by a positive quantum leap.
NG is the only gas accepted for use in machinery spaces, as it is lighter than air and any leaks will not accumulate in the bilges or lower compartments.

The following figure 1 graphs offer a qualitative perspective of Diesel versus Natural Gas internal combustion engine emissions.

Based on that illustration it is evident that a diesel-fuelled fastferry, on a normal yearly working cycle, will produce as much as its own displacement weight of Carbon Monoxide (CO).

It is not uncommon that an estuarial RoPax vessel of similar proportions to the one herein proposed will carry more than 1000kW of installed power.





STANDARD DIESEL

4000 hours @ 1000kW

CO = (15.5x4000x1000)= **62 Tonnes**
NOx = (7x 4000x1000)= **28 Tonnes**
HC = (1x4000x1000)= **4.0 Tonnes**
PM = (0.15x4000x1000)= **0.6 Tonnes**

NATURAL GAS

4000 hours @ 1000kW

CO = (4x4000x1000)= **16.0 Tonnes**
NOx = (1x4000x1000)= **4.0 Tonnes**
HC = (0.5x4000x1000)= **2.0 Tonnes**
PM = (0.05x4000x1000)= **0.2 Tonnes**

Figure 1 - Diesel v Natural Gas engine emissions in (grams / kW / hour)

1.2 What is Natural Gas (NG)?

Natural Gas is not a single product but a mixture of gases, Table 1. It consists predominantly of a molecule naturally found in the environment, Methane (CH_4). The methane molecule is very stable, neither toxic nor volatile.

Table 1 Typical Composition of NG

Typical Composition of Natural Gas	(%)
Methane	93.17
Ethane	3.26
Propane	0.67
Isobutane	0.27
Isopentane	0.08
Hexanes	0.05
Heptanes	0.03
Octanes	0.01
Carbon Dioxide	0.34
Nitrogen	2.12
TOTAL	100.00

NG is the cleanest of all fossil fuels and is the same gas as used in the home for cooking and heating.

As an internal combustion engine fuel it produces the lowest level of carbon dioxide of all hydrocarbon fuels and is virtually free of sooty particles (particulates), lead and aromatic hydrocarbons like benzene. (Benzene is a known carcinogenic)

When compared to diesel:

- benzene emissions are reduced by 97%.
- no lead or sulphur emissions
- nitrogen oxides emissions are reduced by 80%
- carbon dioxide emissions are reduced by 22%.
- carbon monoxide (CO) emissions are reduced by 76%
- virtually no black smoke composed of particulate matter below 10 microns

1.2.1 What is CNG?

Compressed Natural Gas (CNG) is natural gas pressurised up to 250 Bar.

1.2.2 What is LNG?

When NG is cooled to a temperature of approximately -162°C at atmospheric pressure it condenses to a liquid, Liquefied Natural Gas (LNG).
The liquefaction process removes the oxygen, carbon dioxide, sulphur compounds, and water. The process can also be designed to purify the LNG to almost 100% methane, Table 2.
One volume of LNG takes up approximately 1/600th of the volume of NG.
The density of LNG is of 460 Kg/m3.
LNG is odourless, colourless, non-corrosive, and non-toxic.

Since 1958 LNG is carried by sea in purpose built tankers, Gas Carriers, which to date have a remarkable safety record.

Table 2 Typical Composition of LNG

Typical Composition of LNG*	**(%)**
Methane	95.23
Ethane	4.41
Propane	0.30
Isobutane	0.04
N-butane	0.02
Isopentane	0.00
Hexanes	0.00
Heptanes	0.00
Octanes	0.00
Carbon Dioxide	0.00
Nitrogen	0.00
TOTAL	100.00

* (Courtesy of NG supplier - British Gas, UK)

1.3 Safety Aspects of Natural Gas (NG)

NG is inherently less volatile than petrol or diesel.

It is also lighter than air and in the event of a leakage, it will disperse upwards to the atmosphere rather than forming dangerous pools in confined bilge areas.

The flammability of Natural Gas is only possible within a tight mixture range.
If the NG content in air is less than 5% the mixture is over-rich to burn and if it is higher than15% it is too lean. Figure 2 illustrates the case of a LNG spill.

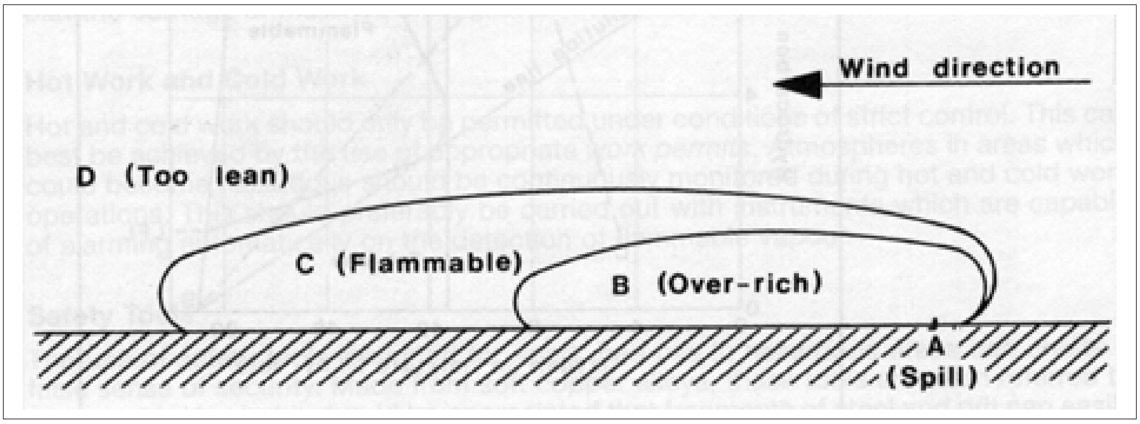


Figure 2 - Flammable Vapour Zones of a LNG spill

Small spills of LNG present little fire risk.
Evaporating LNG warms and floats away, in contrast to other liquid fuel vapors, which linger near the ground.
LNG does not adhere to surfaces as diesel does. Therefore, a fire involving an LNG spill does not mean a fire on anything the LNG contacted.
The low temperature of LNG does its part to retard ignition of the gas. This property can be demonstrated by pouring LNG onto a hot frying pan. No flash fire ensued. NG cannot detonate in unconfined spaces and its ignition temperature is higher than gasoline or diesel, Table 3. A striking match will ignite it, but the coal of a cigarette will not.
If ignition should occur, burning will take place only along the air/gas interface in which flammability requirements are met. In an unconfined space, pressure will not build, and flame speed will be relatively slow.

Table 3 - Fuel ignition temperature comparison

Ignition Temperature	^{o} C
NG	600
Petrol	400
Diesel	250

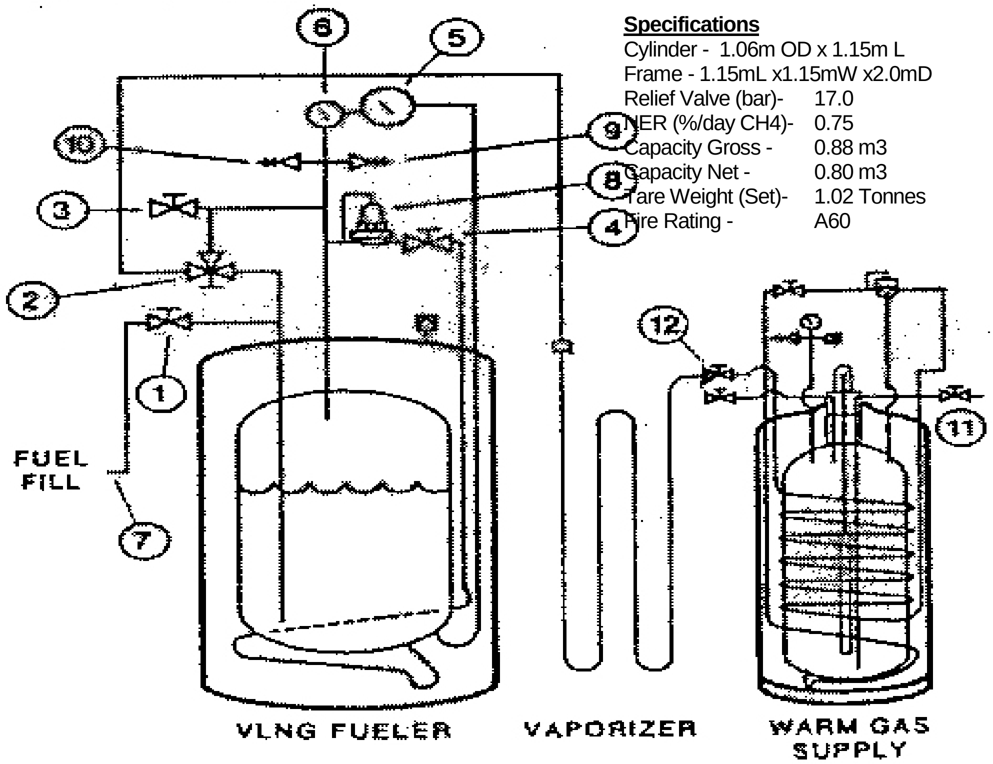
1.4 How is NG stored?

Regarding ship onboard storage, NG can be kept in CNG or LNG state.

NG can be compressed (CNG) and kept in purpose designed pressure vessels. The cylinders are designed to operate at 200 bar and tested up to 250 bar.
The most common materials used are Steel and Composites. The latter have a record of higher incidence in accidental ruptures and leakage.

In the case of a ferry operation the fuel consumption would require a large volume of CNG tankeage, approximately 6 times the volume of Diesel, which may represent a hefty penalty in loss of revenue.

LNG requires less tank space, approximately twice that of diesel and is recognised by authorities as safer.
The tanks are of double-wall construction, efficiently insulated and vacuum-jacketed. They are available in marine specification Stainless Steel, rated to A60.
The standard tank geometry is of cylindrical format with domed ends and will typically sustain pressures from 0.3 to 17 Bar. $1m^3$ units can be stored vertically.



1- Liquid Withdrawal Valve
2- Saturation Valve (3 way)
3- Vent Valve
4- Pressure Building Valve
5- Liquid Level Gauge
6- Pressure Gauge
7- Fill Quick Coupling
8- Pressure Building Regulator
9- Primary Relief Valve
10- Secondary Relief Valve
11- Engine Fuel Line
12- Warm Gas Control Valve

Figure 3 - Typical palletised LNG Fuel Tank : Basic Details

LNG must be maintained cold to at least -50°C to remain a liquid, independently of pressure. To fulfil that requirement the LNG is stored at -190°C as a boiling cryogen, meaning a very cold liquid at its boiling point for the pressure it is being stored, and it will stay at near constant temperature if kept at constant pressure.

The LNG vapour boil off produced during changes of state must be let out to allow the storage temperature to remain constant.
If the vapour is not drawn off, then the pressure and temperature inside the tank will rise, but even at 7 Bar the LNG temperature will still only be circa -90°C.
Figure 3 illustrates a typical 800 litres "off the shelf" LNG storage system.

1.5 Economics of Natural Gas (NG)

US reserves of Natural Gas are estimated to support its projected consumption for much of the 21st century.
Despite its oil reserves the US still relies heavily on imports for much of its energy supply and this reliance can only increase as the reserves become depleted.
Shipping accounts for 30% of oil's global consumption and in developed countries the land transportation sector accounts for another 30%. Governments globally have started to view gas powered transport as an effective means of improving energy security.

1.5.1 LNG v Diesel - Comparative Costs at the time of writing

The basic price of fuel is increased by the accumulative costs of delivery.

The cost of fuel to the ferry operator is effectively the price paid at the hose end when refuelling his vessel. This philosophy applies both to LNG and Diesel.

At the time of writing the price of diesel delivered to a quayside tank in S.Francisco was higher than that of equivalent LNG supplied by truck. Table 4

Table 4 - S.Francisco, Oct.00 - Cost of Diesel v LNG

Fuel Type	Cost per Litre
Diesel*	**$ 0.34**
LNG**	**$ 0.14**

* Ref. Diesel Cost - 3000 Gal bid buy. Info Purchase Dep.t leading ferry operator

** Ref. LNG Cost - 10000 Gal delivery. Info leading local Gas retailer

For the purpose of further quantifying the above cost comparison, with regards to a typical fastferry operation in the Bay Area, the following relations can be used:

- **equivalent work produced - 1 litre of Diesel = 1.75 litres of LNG**
- **equivalent engine performance @ 85% MCR**

From Table 5,

(Diesel Consumption + 17%) = LNG Consumption

Hence,

the actual **LNG equivalent to 1Litre of Diesel** is:

1.75 x 1.17 = **2.048 Litres of LNG**

and

the **equivalent LNG cost** is : 2.048 x $0.14 = **$ 0.28**

Therefore the **cost saving for LNG fuel is** :

(1- ((0.28) : (0.34)) x 100= **17 %**

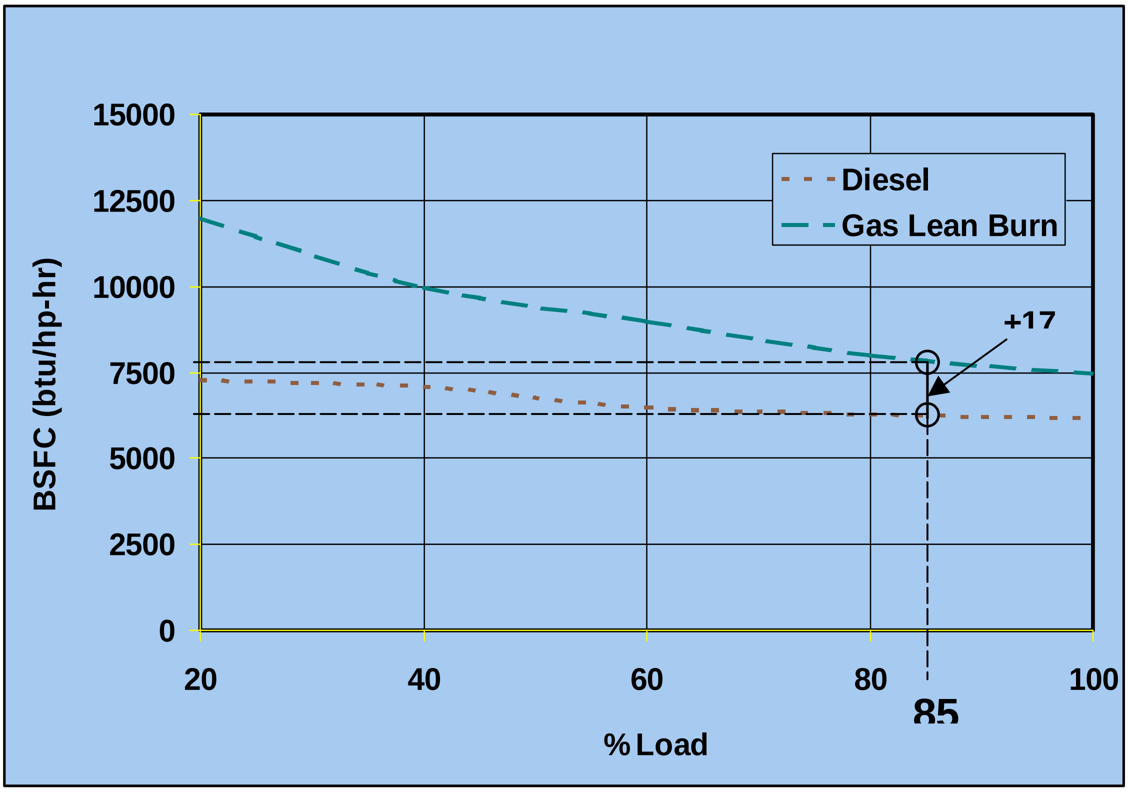


Table 5 - Typical Combustion Engine Fuel Consumption: Diesel v NG

For ease of broad use calculations the following table 6 may be of aid.

Conversion Table : Diesel V Natural Gas **Weight & Volume Equivalents**					
T= 20^{o}C	**Weight**	**NG (N) Normal**	**CNG @ 200Bar**	**LNG**	**Diesel**
Weight	1.00 Kg	1.48m^3	0.0074m^3	0.0025m^3	0.0012m^3
NG (N)	0.67 Kg	1.00 m^3	0.0049m^3	0.0017m^3	0.0008m^3
CNG @ 200Bar	135.7 Kg	201m^3	1.00 m^3	0.3393m^3	0.1621m^3
LNG	400 Kg	593.5m^3	2.952m^3	1.00 m^3	0.48m^3
Diesel	840 Kg	1250m^3	6.16m^3	2.08m^3	1.00 m^3

Table 6 - Conversion Table : Diesel v Natural Gas

Typical LNG / CNG pump
Fill @ 115 litres / minute

1.6 The case for NG fuelled Marine Craft

The high power requirements of a modern ferry represent a serious challenge regarding emission of pollutants from onboard diesel machinery. A study on Marine Exhaust Emissions by Lloyds[4 & 5] quantifies that environmental impact.

Since the emissions from a diesel engine are primarily related to certain design features of that particular engine, it will be for the engine builders to demonstrate compliance with the applicable limits for each engine family being classified.

Many manufacturers have taken that challenge and emissions reduction claims in excess of IMO requirements are stated regularly in the marine specialised press. But those appear to be small gains on the flat peak of a lifetime curve.

By contrast the emerging NG technology offers outstanding performance with only minimal emissions, hence prompting some leading engine manufacturers to embark on the development of the natural gas engine for marine applications.

Those development efforts benefit greatly from the experience of heavy and light fuel oil engine technology, which is a cost effective advantage due to its proven track and inherent strength, durability and reliability built into the basic machinery design.

Putting together specific marine gas engines will require optimisation of several factors such as power, efficiency, emissions, complexity, time and cost; but essentially the core of the work is in place courtesy of the existing combustion engine technology.

It has been common practice for some time on LNG carriers that the power plants installed are of the dual-fuel type being able to use the boil-off gas from the cargo tanks as fuel for ship propulsion. The gas is fed to the dual-fuel boilers instead of being wasted/released to the atmosphere.

Feeding gas into a ship's engine room, a Category A[6] space, calls for well designed piping and control systems supported by effective safety measures. Leading Classification Societies have readily regulated the subject and systems are in place for the classification of LNG Carriers using Cargo as Fuel [7 & 8].

1.6.1 NG fuelled Marine Craft precedents

On the specific subject of a solely NG powered ferry there are no instruments in place for regulation but guidance is available in the form of craft classification precedents and draft recommendations.

The earliest account found by the author refers to a US sternwheeler replica ferry. The James C. Echols, originally built in 1982, with leading particulars 18m LOA, 7m BOA, and 1m draft with a full load of 138 passengers, was upgraded in 1989 from two Caterpillar two-cycle, 180 bhp (135 bkW) diesels to Caterpillar 3406 SINA (spark-ignited naturally aspirated) CNG specific engines, each rated 215 bhp (161 bkW) at 1,800 rpm.

Since CNG had never been approved by the U.S.Coast Guard (USCG) for use on a passenger vessel, the majority of the new work on this project focused on fuel safety, leading to the generation of a set of USCG recommendations[9] for CNG fuel.

RINA's TNA magazine[10], documents the Australian flagged carrier ACCOLADE 2, operated by the Adelaide Brighton Cement Co. and powered from new (1982) by a pair of CNG FUJI engines.

In a more recent issue[11], the article titled "Rising interest in gas fuelled propulsion" clearly indicates the direction and incentives created by the Norwegian Authorities to stimulate their Ferry Transportation Sector.

Finally Fairplay Solutions[12], "Norwegian owner adopts LNG propulsion", brings the subject up to date and details all the more relevant aspects of a new build, the Ro-Pax GLUTRA, fig.4, which started operating in Jan 2000.

An internet search of the Det Norsk Veritas site[13] lead to the following Table 6.

More extensive details regarding the Glutra can be obtained from the leading magazine - The Motorship [14].

Table 6 DNV website download for the Ro-Pax Glutra

Vessel Name	GLUTRA
DNV ID No.	22056
Flag	Norway (NOR)
Ship Type	Car Ferry
Yard Name	LANGSTEN SLIP & BÅTBYGGERI AS
Length Between Perpendiculars (m)	83.59
Length Overall (m)	94.8
Breadth Moulded (m)	15.7
Depth Moulded (m)	5.15

Figure 4 - Artistic impression of the Glutra.

2. AVAILABILITY OF NATURAL GAS ENGINES

Gas engines have been used since the 1930's and were mainly applied in land transport, propelled with town's Gas, when liquid fuels where scarce.

At present most world leading engine makers have sparked Natural Gas variations of diesel based models on their curriculum, with some versions Turbo-Aspirated.

Some brands, namely MTU, Caterpillar and Vickers Ulstein, have embarked in research programs, aiming to optimise and refine their products for particular applications, inclusive of marine propulsion.
Their research is unavailable to the public but details are occasionally obtained. Full extent data releases are expected by the year 2002.

2.1 Otto and Diesel combustion principles

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

	Designation	Lean burn	Combustion principle	Spark ignition system	Prechamber	Only gas fuel	Main gas feed before turbo
Open chamber spark ignited	SG	Yes	Otto	Yes	No	Yes	Yes
Prechamber spark ignited	SG	Yes	Otto	Yes	Yes	Yes	No
Carburettor prechamber ignited	SGC	Yes	Otto	Yes	Yes	Yes	Yes
Prechamber micro pilot	PG	Yes	Otto	No	Yes	No	No
Open chamber dual fuel	DF	Yes	Otto/Diesel	No	No	No	No
Gas diesel	GD	No	Diesel	No	No	No	No
Stoichiometric		No	Otto	Yes	No	Yes	No

Table 7 - Main characteristics for different gas engines

The several characterising features and a nomenclature are described on Table 7.

When an engine works according to the diesel principle the gas fuel is injected after compression of the air in the cylinders, and the heat release is controlled through the combustion phase.
The fuel pressure must have a magnitude of one to two thousand bars.

The most common combustion principle in Otto gas engines is the so called leanburn principle.
The main reasons for choosing the lean-burn combustion concept are its high efficiency, low nitrogen oxide emissions and potential for high power density.

Generally, the leaner the mix the better, until an instability or misfire limit is reached where the hydrocarbon and carbon monoxide increase rapidly, figure 5.

The above emissions can, if needed, be drastically reduced using various after-treatment devices.

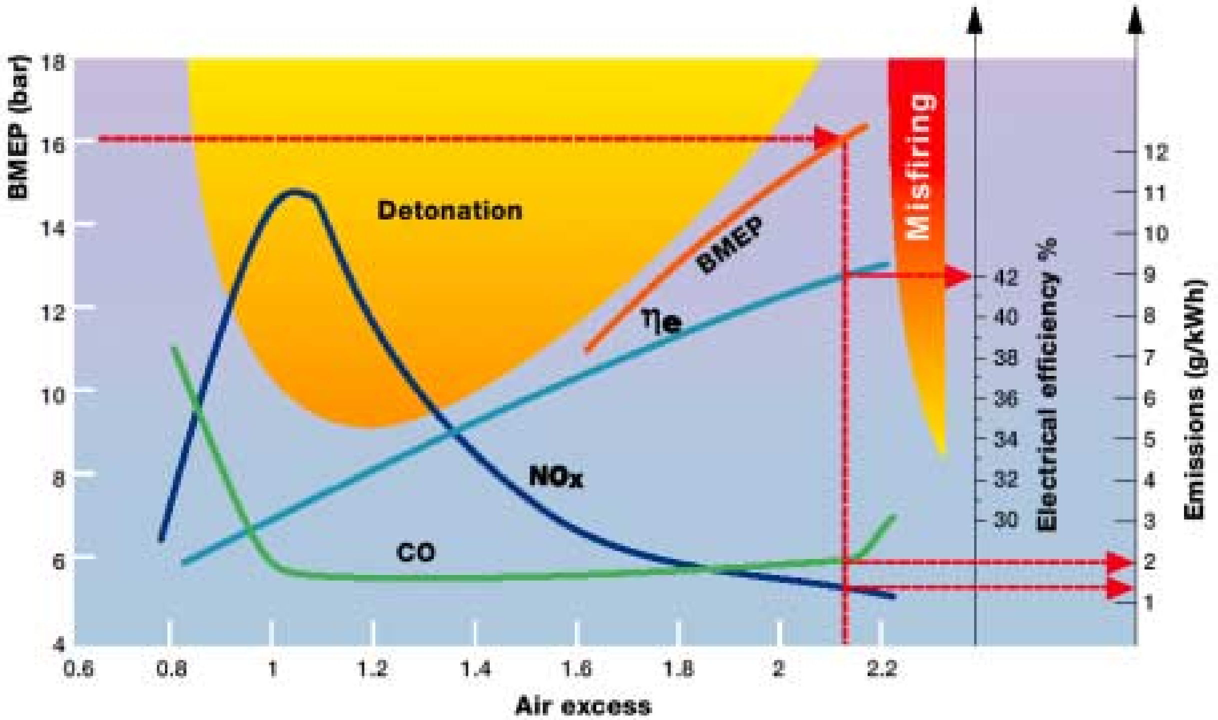


Figure 5 - Otto Gas Engine Efficiency Chart

Modern Otto and Diesel gas engines have roughly the same efficiency.

The output power of an Otto engine is restricted due to knocking, while the diesel version requires a more costly fuel system and has higher emissions.

A typical Sankey diagram for a gas/electric genset is illustrated in figure 6.

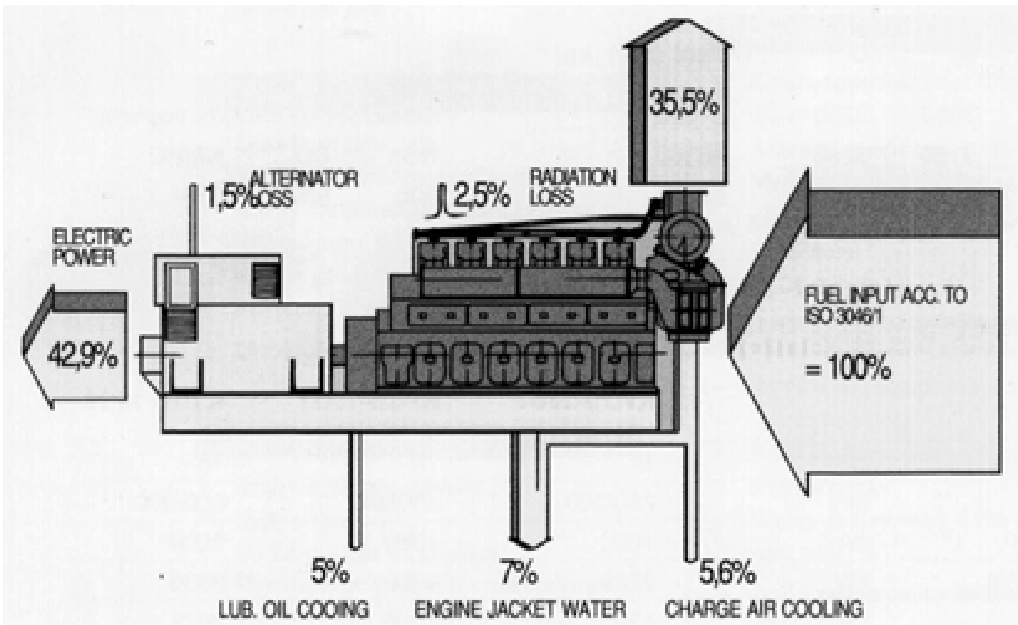


Figure 6 - Typical Sankey diagram for Gas/Electric Genset

In general variable speed gas engines produce full torque down to 70% of rated maximum speed and then reduce approximately linearly.

Use of natural gas as the primary fuel yields cleaner lube oil and reduced engine wear. This will imply direct cost savings in increased time between overhauls and it also extends the economic life of the engine, which means a greater overall return per vessel.

The basic issue regarding the use of gas engines for marine propulsion is though the non-availability of powerplants capable of matching the perceived standard of transient response commonly provided by diesels in mechanical drive applications.

In simplistic terms, an equivalent power gas engine would stall or produce high emissions if subjected to the same transient load variation a diesel withstands.

The fuel and combustion systems of the gas engines are mostly optimised for a narrower band of their power curve, as required by electrical machinery, Table 8.

Gas Engine Manufacturers	**Power Band (kW)**	**Turbo-Charged Normally Aspirated**	**Application**	**Class Rated**
Caterpillar	100 - 4000	Turbo-Charged Normally Aspirated	Power Generation Road Transport	No
Cummins	100 - 300	Turbo-Charged Normally Aspirated	Power Generation Road Transport	No
Jenbacher	150 - 2700	Turbo-Charged	Power Generation Rail Transport	No
Deutz - MTU	250 - 1400	Turbo-Charged	Power Generation	No
Ruston -Alstom	900 - 4300	Turbo-Charged	Power Generation	No
Vickers-Ulstein	1000 - 7000	Turbo-Charged	Power Generation	No
Wartsilla	690 - 2070	Turbo-Charged	Power Generation	No
Waukesha	75 - 3300	Turbo-Charged Normally Aspirated	Power Generation	No
Mitsubishi	300 - 2000	Turbo-Charged	Power Generation	Yes DNV

Gas
/Ele
ctric

Table 8 - Leading power plant makers with NG industrially rated units

Gensets have been extensively tested and are well acknowledged for offering low emissions and good fuel economy within their designated range.

Courtesy of the electric motor and its associated control characteristics a superior transient response can be achieved from an electric transmission. Note that traditionally a 10% power loss is accounted for between alternator and propulsor.

Thus a fixed speed gas/electric drive provides the best compromise in adapting the existing crop of gas engines to marine propulsion, at present.
Unavoidably there is a heavy penalty in additional weights regarding electric items.

The following Table 9 quantifies, for indicative purposes, the additional weights of Generator, Electric Motor, Control Cabinets and Cabling, accrued by an electric propulsion installation for a propeller shaft power output between 0.5 / 1.0 kW.

Electric Propulsion (0.5 / 1.0 kW)	**Item Weight (Tonnes)**
Electricity Generator	2.35
Electric Motor	2.10
Control Cabinets	0.70
Wiring and Cabling Installations	2.90
Other related fittings	0.45
TOTAL	8.50

Table 9 - Itemised Additional Weights per GenSet for Marine Electric Propulsion

2.2.1 How are the engines Classified for marine use

To ensure that the engines comply with marine standards, it is required that they be tested by the flag state or by a body, such as a classification society, appointed by the flag state.

The engines are tested either individually or divided into families or groups where only the parent engine is tested.
The certificate of the member engine is then based on the test carried out for the parent engine.
The actual test can usually be carried out in connection with normal workshop engine tests.

After successful testing and approval of the documentation, the engine is supplied with an interim statement of compliance that is formalised at a later stage.

2.3 NG fuel system impact on Vessel Safety

The approval of a novel concept for public use remains terminally at the discretion of the Classification Society and State Authority powers.

2.3.1 The view of the Classification Society

On pre-consultation of Lloyds Register it was indicated that for purposes of classification and approval the IGC Code[10] would be adapted on any aspects related to the use of NG as machinery fuel.

Other leading classification societies expressed a similar view.

The following set of Plans is required for classification

- General Arrangement
- Gas Piping System and details of Interlocking and Safety Devices
- Gas Heater Plan
- Gas Storage Pressure Vessels
- Gas Fuel Burning Arrangements

All LNG equipment is to be A60 Fire Rating compliant.

The salient IGC Code[10] aspects regarding the use of gas as fuel are as follows:

2.3.1.1 Only Natural Gas can be used as ship's propulsion fuel.

2.3.1.2 Category A spaces are to be fitted with mechanical ventilation arranged in such way that no dead spaces can occur.

2.3.1.3 Gas Detectors to be fitted, and to activate at 30% of the gas Lower Flammable Limit (LFL), and shut-down the Master Fuel Valve before a concentration of 60% LFL occurs.

2.3.1.4 Pressure of the gas supply to the machinery space to be less than 7 Bar and gas temperature to be approximately the same as ambient.

2.3.1.5 Gas Fuel Piping not to pass through Accommodation Spaces, Service Spaces, or Control Stations.

2.3.1.6 Gas Fuel Piping to be of double wall concentric type, with inert gas between the inner and outer pipe, i.e. nitrogen, and at a greater pressure than the gas fuel pressure.

2.3.1.7 Ventilation Hoods or Casing provided for the areas occupied by flanges, valves, etc.

2.3.1.8 Automatic Fuel Shut-Down in case of gas leak

2.3.1.9 Local Manual Shut-Offs arrangements included

2.3.1.10 Electrical Equipment in risk areas to be of the Intrinsically Safe type

At the time of writing a DNV Rule Proposal draft titled "Gas Fuelled Engine Installations" is undergoing review for probable implementation by Feb 2001. It is important to note that this proposal is at this moment not specific to fast ferries.

2.3.2 The view of the State Authorities

On pre-consultation of the UK Maritime and Coastguard Agency (MCA) it was stated that due to the unprecedented nature of an NG Ferry project a Failure Mode and Effect Analysis (FMEA) risk assessment method should be designed.

The onus of demonstrating the safety of operation would be on the user / owner / operator.

A seemingly apt FMEA system is under review by the USCG[10]

3. DESIGN OF AN ESTUARIAL NG POWERED RO-RO FERRY

A ferry operation is intrinsically part of a wider transport network and has to accommodate present and projected levels of punctuality, service reliability, economy, travelling comfort, speed, safety and environmental friendliness.

Also, the use of an alternative fuel and power plant on a small rapid transport vessel generates repercussions throughout its design, namely on safety, layout and structure.

Taking the above into account the design evolved towards a slender catamaran platform, which is seen as competent in offering a good compromise overall.

With a view to minimise weight and achieve an adequate operating displacement, stability, strength, hull form and speed, a Top-Down design analysis is adopted.

Hence, in broad terms, the superstructure is designed first and the hull, deck and machinery are then reversibly fitted and iterated to best compromise.

The design is carried out under the Lloyds Rules for Special Service Craft, which cater specifically for fast, lightly constructed vessels built in aluminium and which are intended to carry fare-paying passengers.

In line with modern thinking mobility deficient passengers are accounted for.

Regarding machinery power the design evolved towards the application of a Gas/Electric prime mover arrangement, where the NG engine runs an electricity generator which powers an electric motor connected to the propeller shaft propulsion train.

This arrangement's cons are that it is initially more expensive and it is heavier than a mechanical drive.

Its merits include:

- Ease of control, providing excellent manoeuvring capability
- Ability to operate economically for lengthy periods at reduced speed/power.
- High degree of redundancy
- No mechanical links between power plant and propulsor, generator set can be placed to best compensate the vessels trim.

3.1 BASIC SPECIFICATIONS DRAFT

The specification herein details the main design parameters of the ROPAX Estuarial NG Powered Ferry.

3.1.1 Flagstate

United Kingdom, certified to carry 60 Passengers

3.1.2 Classification

Lloyds Register of Shipping

- Special Service Craft Rules
- +100-A-1 Ro/Ro Passenger Ferry, +LMC, UMC

3.1.3 Damage Stability Standards

- International Code of Safety High Speed Craft (HSC Code)
- SOLAS 90 (2 Compartments) + Stockholm Agreement
- MCA Category 3,4,5,6

3.1.4 Main Dimensions

Length Overall (LOA) -..not greater than 27.0 m

Length Between Perpendiculars (LBP) -.. 25.0 m

Breadth Overall (BOA) -...not greater than 13.0 m

Depth (D) -..not greater than 10.0 m

Design Draught (T) - ....not greater than 1.8 m

3.1.5 Deadweight

Deadweight at Design Draught - .... 16.0 T

3.1.6 Vehicle Capacity

Total Car Lane Length .... 50.0 m

Car Lane Width ....2.3 m

Air Draught over Lanes..2.3 m

3.1.7 Deck Loads

Maximum Axle Load .... 0.8 T

3.1.8 Passenger Capacity

Seating Capacity 60

3.1.9 Main Public Spaces

Bar/Lounge.. 10.0 m^2

3.1.10 Speed

Trial speed at design draught to be 25 Knots with main engines run at 85% MCR

3.1.11 Propulsion

Prime Movers...2 off NG/Electric Genset installation

Propulsors ....2 off 5 bladed Fixed Pitch Propellers (1 each demihull)

3.1.12 Intended Operation Cycle

The envisaged ferry operation obeys to the following working pattern:

No.	ACTION	APPROXIMATE TIME	TOTAL
1	Load Pax & Vehicles	5.0 minutes	5 minutes
2	Departure / Manoeuvre	2.5 minutes	25 minutes
3	Route A to B	20.0 minutes	
4	Arrival / Manoeuvre	2.5 minutes	
5	Unload Pax & vehicles	5.0 minutes	10 minutes
6	Load Pax & Vehicles	5.0 minutes	
7	Departure / Manoeuvre	2.5 minutes	25 minutes
8	Route B to A	20.0 minutes	
9	Arrival / Manoeuvre	2.5 minutes	
10	Unload Pax & vehicles	5.0 minutes	5 minutes
11	**Total Turn Around Trip**		**70 Minutes**

Note: The vessel stops once every hour at the pump end for 10 minutes. Unloading / Loading doubles-up as Refuelling slot.

3.2 GENERAL ARRANGEMENT (GA)

The greatest determinant on the GA is the vessel's purpose.

At present a ferry design is marketed and sold on its merit to satisfy the end user, which implies the passenger and vehicle areas have to be attended to first.

It is important that the arrangements are attractive, encouraging repeated use of the ferry, and that the payload of passengers and vehicles are loaded / unloaded quickly, efficiently and safely, for a successful service outcome.

The GA outlines the basic geometry and factors such as structural weights, machinery layout, fit out, etc., are subsequently derived from it in iterations.

Hence the GA is herein developed in interaction with a tentative structural mid-ship section, leading to a weight estimate and the final generation of a lines plan.

3.2.1 Superstructure

After iteration through LRSSC the superstructure is deemed as structurally ineffective regarding contributing to the vessel global strength.

Its main purpose is thus of enveloping the passenger areas, car deck and bridge.

3.2.1.1 Passenger Cabin

Access to the upper cabin is via two stairwells aft, Port and Starboard, and one lift for the mobility deficient.

Accommodating 60 in a mix of seat and table islands and standard pitch seat rows, aiming at the modern informal traveller, as cultivated in intercity train culture.

A Luggage isle is placed at the aft entrance.

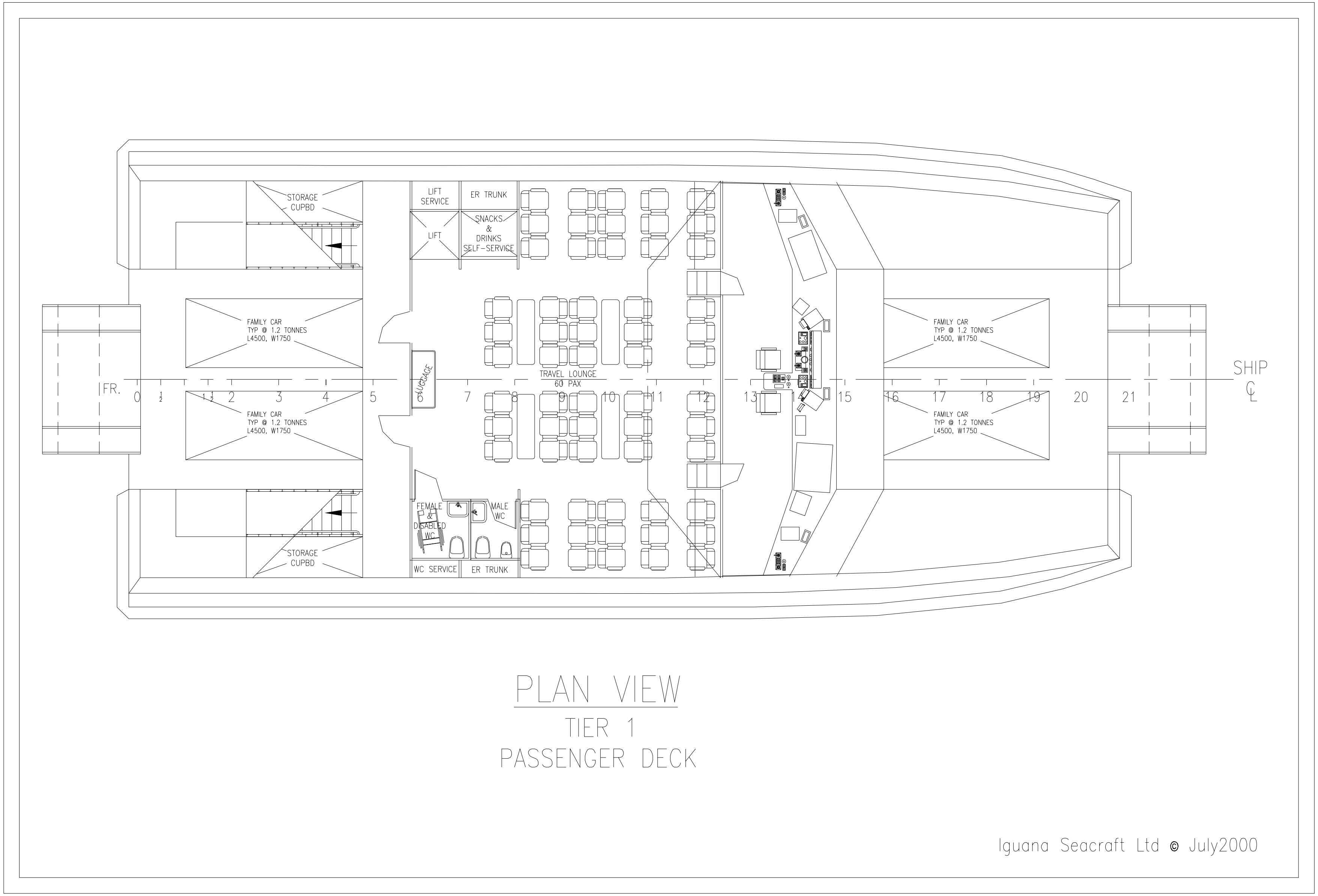
A stand-up café kiosk is included and a drinks trolley can circulate conveniently.

Two male/female toilets are provided catering equally for crew and wheelchairs.

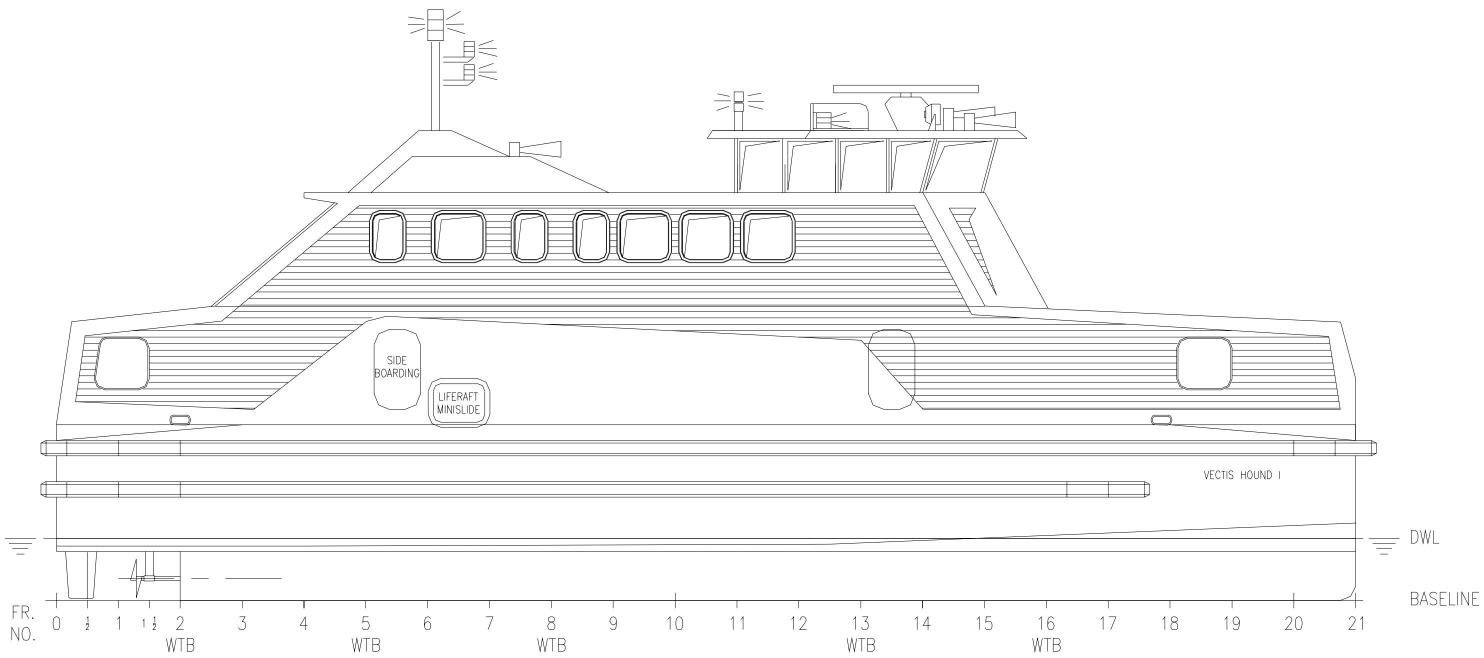
With regards to fire safety, the passenger compartment shall be fitted solely with certified Fire Resisting Materials, and covered by a sprinkler system triggered by smoke alarms. Adequate evacuation means are provided in compliance with the HSC code and the MCA statutory requirements.

3.2.1.2 Bridge

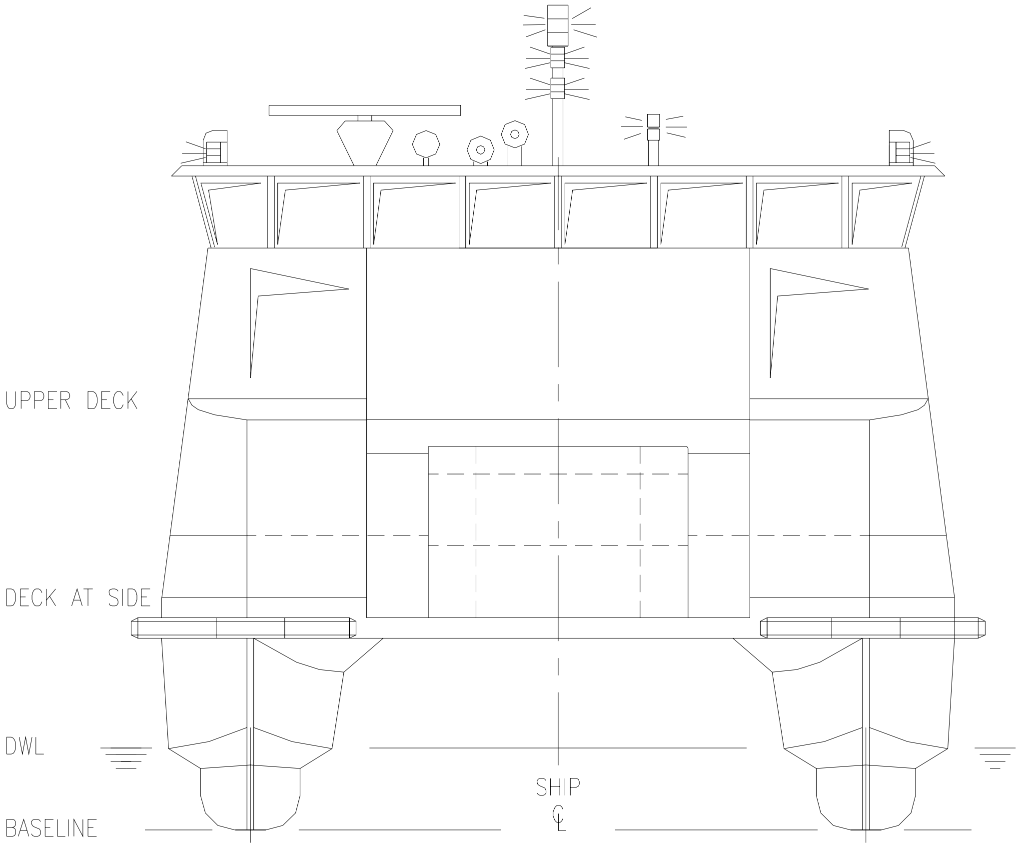
The uncluttered layout of this operating compartment is in line with current concepts of human error minimisation through ergonomic design in addition to the standard HSC requirements. The field of vision from the operating station offers 360 degrees visibility over the horizon and there are two docking stations for close quarters manoeuvring when coming alongside or casting off. Access to the compartment is through the passenger cabin via two centrally located access doors. These are lockable for operational convenience.



STORAGE CUPBD
LIFT SERVICE
ER TRUNK
LIFT
SNACKS & DRINKS SELF-SERVICE
FAMILY CAR TYP @ 1.2 TONNES L4500, W1750
LUGGAGE
TRAVEL LOUNGE 60 PAX
FR.
0 ½ 1½ 2 3 4 5 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
SHIP ℄
FEMALE & DISABLED WC
MALE WC
WC SERVICE
ER TRUNK
STORAGE CUPBD
PLAN VIEW
TIER 1
PASSENGER DECK
Iguana Seacraft Ltd © July2000



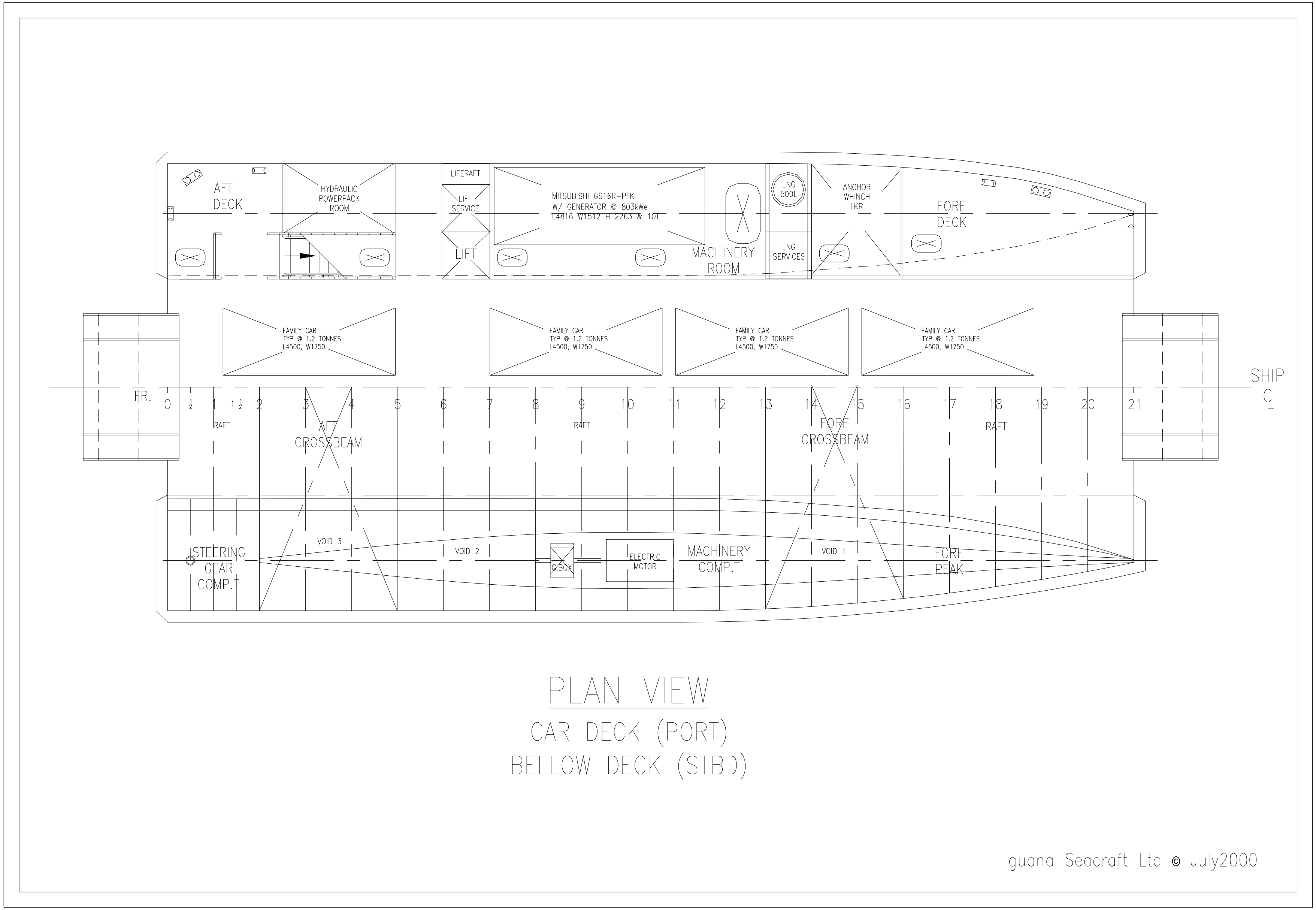
PROFILE VIEW



END ELEVATION
LKG AFT

VESSEL PARTICULARS

NAME..................	VECTIS HOUND 1
TYPE....................	SLENDER CATMARAN
CLASSIFICATION...	LR SSC
CONSTRUCTION....	ALUMINIUM
LOA.....................	25.20 M
BOA....................	12.50 M
DRAFT..................	1.35 M
DEPTH................	11.50 M
PRIME MOVERS....	2 OFF @ 800kW EA
PROPULSION........	GAS/ELECTRIC
PROPULSORS.......	2 OFF 5 BLADED FPP
SERVICE SPEED...	25 KTS
PAX.NO................	60
VEHICLES.............	8 LGV'S


AFT DECK
HYDRAULIC POWERPACK ROOM
LIFERAFT
LIFT SERVICE
LIFT
MITSUBISHI GS16R-PTK
W/ GENERATOR @ 803kWe
L4816 W1512 H 2263 & 10T
MACHINERY ROOM
LNG 500L
LNG SERVICES
ANCHOR WHINCH LKR
FORE DECK
FAMILY CAR
TYP @ 1.2 TONNES
L4500, W1750
SHIP ℄
FR. 0 ½ 1 1½ 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
RAFT
AFT CROSSBEAM
FORE CROSSBEAM
STEERING GEAR COMP.T
VOID 3
VOID 2
G.BOX
ELECTRIC MOTOR
MACHINERY COMP.T
VOID 1
FORE PEAK
PLAN VIEW
CAR DECK (PORT)
BELLOW DECK (STBD)
Iguana Seacraft Ltd © July2000

3.2.2 Car Deck

The need to carry light goods vehicles of several shapes and sizes dictate the car deck layout. Since a ferry's service life cycle aims at a 20-year span the layout of the car deck has to incorporate a certain amount of flexibility, accounting for changes to vehicle shape, culture and use.

The present proposal takes account of mobility impaired and handicap drivers, providing 2 easy access car bays within the total 8 off available.

Wide side access passenger alleys are incorporated and the centreline car lane separation allows for doors to be released without damaging the nearby vehicle.

The open deck option is weight conscious and covered by a sprinkler system triggered by smoke and heat sensors.

The parking space geometry is in line with recommended car bay planning practice, whilst respecting Load Line Regulations and the HSC.

Structurally the deck face has to be able to bear 0.8 Tonnes Single Axle Loads.

3.2.3 Machinery Room

One advantage of the Gas/Electric Generator it is its modular pack format.

A sound insulated, fire and blast resistant enclosure containing the gas engine and alternator can be flexibly mounted to the bulkhead deck surface.

All cabling and piping are interfaced and can be connected/disconnected, making it easier for inspections and maintenance.

With these circumstances in mind the design caters for easy installation/removal of the power pack unit, for convenient on shore servicing.
For safety, the air volume within the enclosure is renewed 30 times every hour and a gas leak detection system trips the engine off, if activated.

3.2.4 LNG Tank Compartment

Two fire and blast resistant enclosures port and starboard, containing the LNG tankeage and services can be easily accessible from inboard and outboard.

All cabling and piping are interfaced and can be connected/disconnected, making it easier for inspections and maintenance.

For safety, the air volume within the enclosure is renewed 30 times every hour and a gas leak detection system trips the engine off, if activated.

3.2.5 Propulsion

Propulsion is provided by two gas/electric engine sets of the owners choice, each one developing 800kWe at 85% maximum continuous rating 1500 RPM, coupled to synchrogenerators by STN ATLAS.

The propeller drive motors are also by STN ATLAS.

The exhaust temperature, 410^{o} C at the manifold allows for complementary heat extraction to supply the vessel's heating system. The gas temperature can be reduced to approximately 120^{o} C, lower limit for condensation, and subsequently let out to the atmosphere.

3.2.6 Vessel Construction Details

The hulls are connected by a flat bridging structure incorporating 2 main transverse beams positioned at the aft and forward ends.

Special category areas (vehicle decks) and machinery spaces (engine rooms) are clad with structural fire protection.

The vessel is generally of all aluminium construction framed on a longitudinal system. Structural plating and frames are fabricated from aluminium alloy type 5083-H321 and extruded sections are 6061-T6 or those approved by the survey authority.
Frames are generally spaced at 1200 mm centres throughout the vessel and bulkheads provide six watertight compartments in each demihull. (Table 10)

Table 10 Hull Compartmentation

Forepeak	including forward ride control where fitted
Void 1	including long range fuel tank where fitted
Electric Drive Room	Propulsion Machinery
Void 2	including 2 sprinkler pumps P & S
Void 3	including holding tank (starboard side), lubricating oil and fresh water tank (port side).
Steering Gear Room	hydraulics (and ride control system where fitted)

4. NG PROPULSION FOR FASTFERRIES

The quickest developing sector of the marine industry is the fast ferry business, transporting people goods and vehicles in high speed vessels.

While some existing ferry operators are looking to up-grade their craft to keep up with impending legislation, many new ferry start-up services are being proposed and will only succeed if a sustainable long-term future can be envisaged.

It is to the latter NG propulsion will hold promise.

4.1 - Opportunities

- Natural Gas has great public appeal
- It is cheaper than diesel and price will lower with increase of supply
- Classification is immediately possible on certain areas and routes
- New pastures for naval architecture, vessel design and marine engineering due to alternative requirements of power plant, fuel system and transmission.

4.2 - Threats

- Initial opposition from diesel market supporters
- Initial higher expense on machinery, parts and systems
- Initial higher expense on unprecedented classification and regulation
- Initial higher expense in personnel education and training

5 - Conclusion

The success of highspeed NG propulsion is invariably going to depend on the development of gas engines and transmission trains for high speed craft.

The supply of NG to the operating scenarios will play an important role but will be unavoidably established in empathy with land transportation.

The eagerness of authorities, regulatory bodies, naval architects and operators will have the final impulse to how quickly can Natural Gas be put to work.

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