Environmental aspects of natural gas application in inland water transportation

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Current interest in developing the inland water transport leads to a considerable increase in motorized water vehicles. More units mean more emissions and pollution. Therefore, the increment of water traffic should associate with a lot of regulations to impose wider and tighter controls on environmental aspects. A successful way for achieving significant economical development and good environmental impact is by switching from traditional oil based fuel to Natural Gas (NG) fuel. The national NG operational record is attractive and its cost is competitive. The infrastructure and distribution network of NG is covering and serving most of areas around the inland waterway. The objective of the present work is to establish a proposal to use the national NG as an environmental friendly and unique fuel for the propulsion machinery of the inland water transport vehicles. The paper covers the situation of national NG, the gas storage systems, safety and environmental impacts, NG infrastructure and refueling stations. The regulations and classification society requirements to control the gas engines installation and arrangement are discussed. The study proves that, the GN is ideal and unique future fuel in the country.

إن تطوير و تحديث النقل النهرى فى مصر يتطلب تحسين البنية الأساسية للمجرى الملاحى و زيادة عدد الوحدات النهرية وقدراتها و لكن سوف يصاحب ذلك زيادة مطردة فى حجم الانبعاثات الغازية و الملوثات حول المجرى الملاحى. الأمر الذى يتطلب ضرورة وجود قوانين و معايير كافية لحماية البيئة.و الحفاظ عليها و لعل من افضل الحلول لتحقيق البعد البيىء و الاقتصادى معا هو الحد من استخدام وقود الديزل التقليدى و استبداله بالغاز الطبيعى كوقود نظيف صديق للبيئة اثبت كفاءة عالية فى محركات النقل البرى و خاصة أن البنية الأساسية للغاز الطبيعى تتوافر على طول الخط الملاحى. و فى البحث الحالى تم دراسة استخدام الغاز الطبيعى فى محركات النقل النهرى كوقود صديق للبيئة حيث يناقش البحث إمكانيات الغاز الطبيعى بمصر بما فى ذلك طرق التخزين و الأمان على الوحدات النيلية و كذلك التوزيع الأمثل لمحطات التموين و الوقود على طول الخط الملاحى بالإضافة إلى احتياطات تجهيز و توزيع غرف المحركات و توافق ذلك مع هيئات الإشراف الدولية. و قد اثبتت الدراسة ان الغاز الطبيعى هو وقود المستقبل الاوحد فى مصر.

Keywords: Inland water transport, Natural gas, River vehicles, Refueling station

1. Introduction

In last 80’s, the Egyptian Government built El-Dikheila Port in order to facilitate larger sea going vessels and deems suitable to serve for inland water transport. In this respect, a feasibility study carried out to connect El-Dikheila port with the greater Cairo for possible transportation of about 6 million tons per year. Based on the future demand projection formulated by Japan International Cooperation Agency (JICA) and River Transport Authority (RTA) study team [1], the major cargo expected from El-Dikheila port to be transported by inland waterway in future is containers and bulk cargoes. The best alternative choice for consideration is opening a coastal connection between Alexandria and El-Dikheila by introduction of newly designed coastal inland water sailing barges.

In July 2000, Ministry Of Transport (MOT) has made an OT basis contract with Egytrans for development of Cairo based container terminal at Ather El-Nabi port in Cairo. This development project expects to handle 25000 TEU containers in the first phase. The 2nd phase development, will establish another container route from Damietta port, to achieve a target of 75000 containers/year. Besides, MOT has announced that river container terminals will be established along river Nile in Abu Zaabal, Asyut, and Qena [2].

According to the programme and future plane of RTA and MOT, the river vehicles and inland water unites will increase rapidly. A considerable large number of self propelled barges and new motorize water vehicles and tugs are expected. Additionally more than 4354 existing vehicles are already running along the waterway, according to RTA reports [3,4]. The power installed in the above mentioned units are ranged from 50 to 1000 horsepower. Most of these units are owned and operated by public sectors. At the same time, most of the locations and cities around the River Nile are suffering from heavy traffic road transport and exhaust emissions concentration. More efficient machinery concepts and emission reduction technology, such as direct water injection and selective catalytic reduction units, have already made it possible to reduce some emissions. That is mean, the environmental aspects and propulsion machinery concepts should be one of high importance issues, associated with the development of IWT and the used fuel have to be environmentally friendly.

However, more drastic means are required to cut all relevant exhaust emissions, including CO_x & NO_x, from inland water vehicles. One way to do this is by switching from traditional oil based fuel to Natural Gas (NG) fuel. Operating on NG results in very low emissions owing to the clean burning properties of gas and the fuel's low content of pollutants. NG consists mainly of methane, the most efficient hydrocarbon fuel in terms of energy content per amount of carbon.

The objective of the present work is to establish an environmentally friendly proposal to improve and develop the inland water transport with minimum possible emissions. The paper aims to use the national NG as an environmentally friendly fuel for the propulsion machinery of the inland water transportation vehicles. NG as fuel is well established successfully in urban transport and power generation sectors and that technology can transfer in sympathy to the inland water transport vehicles. The international record of the few vessels used NG is encourage. Also, the cost of national NG is competitive with Diesel Oil (DO). Additionally, the NG infrastructure and pipe line network covering and serving most of areas around the inland water way. The proposed study will focus on the national gas production, IWT vehicles, the gas storage systems, safety aspects, environmental impact, the gas engines and machinery arrangement.

2. Situation of national natural gas

NG was introduced to the Egyptian local market in 1975 when the first Natural Gas field Abo-Madi was put on stream, since then a remarkable progress has been achieved. The proven gas reserves are 1.9 Tm^3 at March 2005. The cumulative gas production till July 2004 is 0.41 Tm^3 and the gas consumption is around 30.8 billion cubic meters from July 2003 till June 2004 representing about 47% of the primary energy consumption in the country.

Fig. 1. shows the Egyptian NG production from 1980 up to 2005 which reflects the ascending production rate. The proven reserve of NG in billion cubic meters is plotted in fig. 2. Figs. 1 and 2. indicate that the production rate of NG is less than the required target, therefore, the government and the petroleum sector should be provided more effort and action to enhance the investment in exploration, development of gas fields, production activities and open more markets and consumption sources of gas.

2.1. Local NG infrastructure

A high efficiency gas transmission network of about 14000 km including high and me

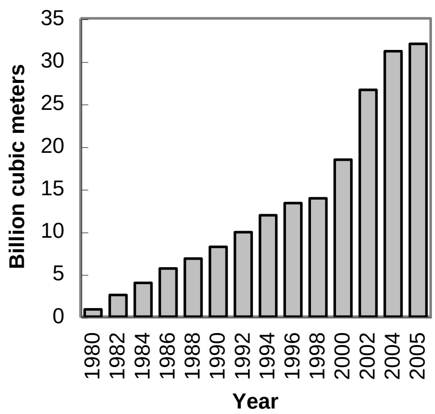

Fig. 1. Egyptian natural gas production from 1980 to 2005.

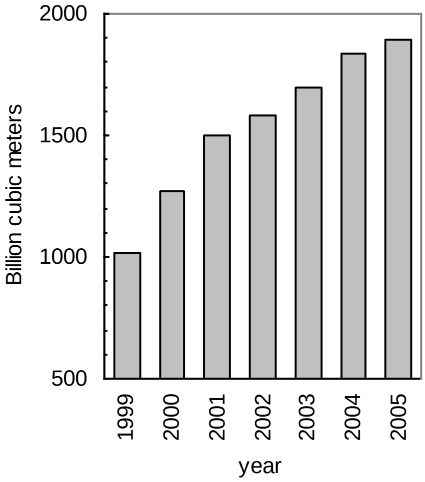

Fig. 2. Egyptian natural gas proven reserves.

dium pressure in addition to internal/ external installations for industrial and domestic consumers and a capacity of 135 millions m^3/ day has been gradually established to support the expansion of gas market. Upgrading and expanding this transmission network is taken into consideration, to satisfy the ever increasing local demand on gas, being the fuel of choice on the long run. In addition, availability of such flexible gas grid is definitely major support to generalize the gas as a unique fuel for all the vehicles in the country [5].

Power stations, domestic and commercial consumers represent a growing market of gas, about 62% of total gas utilized for power generation. In additional, 2 million residential and commercial customers are currently supplied by NG. Now 11 gas distribution companies are involved in gas distribution business over the country. Also, 54200 vehicles are using NG as a fuel; about 83 fueling stations are in operation over the country. Egypt is among the first 10 countries conducting clean fuels programs based upon the total number of CNG powered vehicles [5].

3. Environmental impact of natural gas versus diesel oil

Diesel engines are significant contributors to air pollution. Diesel exhaust contains over 40 chemicals that are listed by the U.S. Environmental Protection Agency (EPA) as toxic air contaminants [6].

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.

The diesel oil versus natural gas engine emissions is tabulated in table 1. The table indicates the great benefit of the NG option. The reduction values of CO_x emissions can not be achieved when burning any other oil based fuels. Also the lack of particulates in NG fuel eliminates 50% of PM emissions, while the clean burning properties of a lean burn gas engine reduce the NO_x emissions to a fraction of those produced by a conventional diesel engine [7], see fig. 3.

Table 1
Diesel oil versus natural gas engine emissions and reduction percentage

Emission	Value (g/kw/hr)		Reduction %
	Standard DO.	Standard NG.	
CO_2	830	642	22.6
CO	15.5	4.0	74.0
NO_x	9.8	1.0	89.7
HC	1.0	0.5	50.0
PM	0.15	0.05	66.6

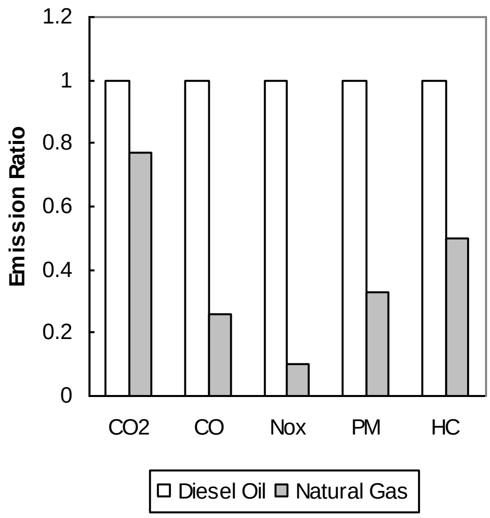

Fig. 3. Relative exhaust emissions of an engine fueled by NG v DO.

4. Classification societies requirements and regulations

The classification society's regulations and rules are issued only to cover the installation of Dual fuel natural gas engines onboard vessels over 90 meters in length and intended to carry liquefied or compressed natural gas in bulk. These vessels used its boil-off cargo as a fuel [8-10]. Since there is no specific regulations and rules for small vessels used NG in inland water transportation, then it is preferable to follow and apply the same rules and regulations requirements on the installation of NG engines on sea going ships.

4.1. Safety aspects of 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%, Lower Flammability Limit (LFL), the mixture is too lean to burn, and if it is higher than 15%, Higher Flammability Limit (HFL), it is over rich. NG cannot detonate in unconfined spaces and its ignition temperature is higher than gasoline or diesel, see table 2. 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 [11].

4.2. NG fueled inland water vehicles

On the specific subject of NG applications in IWT, there are no instruments in place for regulation but guidance is available in the form of other marine units running safely. The earliest account was the Australian carrier Accolade2 lunched in 1982 [12], powered by a pair of CNG engines. In 1985 and 1988 two passenger/ vehicle ferries, Klatwa and Kullet, where converted from diesel to Dual fuel operation [13]. In 1989 US stern wheeler ferry was upgraded from two Caterpillar diesel to two Caterpillar CNG specific engines. More recently [14] the new build Ro-Pax Glutra designed specifically for LNG fuel, is operating successfully since Jan 2000. A new high Ro-Pax vessel was designed for dual fuel Electric propulsion system in 2002, [15].

The application of NG into a ship requires a well design of piping and control systems supported by effective safety measures. The classification societies have readily regulated the similar systems and mechanisms are in place for the classing of LNG carriers using cargo as a fuel.

Table 2
Properties of NG v DO

Items	DO	NG
Ignition temperature, °C	250	600
Density, kg/m^3	850	0.74
Calorific value, kj/kg	46000	54300

4.3. Gas engine installation

On pre-consultation of Lloyds Register and DNV it was indicated that for purposes of classification and approval the IGC Code [16] would be adapted on any aspects related to the use of NG as machinery fuel. Other leading classification societies expressed a similar view. The general arrangement, gas piping system and details of interlocking and safety devices, gas heaters, gas compressors, descriptions for control and monitoring system, details of all electrical equipment, gas storage pressure vessels, gas fuel burning arrangements, should be provided and submitted. All NG equipment is to be A60 fire rating compliant. The salient IGC Code aspects regarding the use of gas as fuel are summarized in the following points:

- Only Natural Gas can be used as ship's propulsion fuel.
- Category A spaces are to be fitted with mechanical ventilation arranged in such way that no dead spaces can occur.
- Gas Detectors to be fitted, and to activate at 30% of the gas (LFL), and shut-down the master fuel valve before a concentration of 60% HFL occurs.
- Pressure of the gas supply to the machinery space to be less than 7 bars and gas temperature to be approximately the same as ambient.

• Gas fuel piping not to pass through accommodation spaces, service spaces, or control stations.
• 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.
• Ventilation hoods or casing provided for the areas occupied by flanges, valves, etc.
• Automatic fuel shut-down in case of gas leak and local manual shut-offs arrangements included electrical equipment in risk areas to be of the intrinsically safe type.
• Gas detectors should be located in strategic locations to quickly detect any gas leak
• In large propulsion power plants, the engine located in two separate engine rooms with a cofferdam in between to minimize the consequences of gas leakage in either engine room

5. Storage of natural gas onboard ship

The NG may be storage onboard ship in two states according to required weight and volume beside the specific design and operation of the gas engine.

5.1. Compressed natural gas on board storage

CNG is storage in purposely built pressure vessels, normally operating at 200 bars and tested up to 250 bars. The most common materials used are Steel and Composites. The outer shell of the vessel has an energy absorbing material that protects cylinder from abrasion. In the ship operation the fuel consumption would require a large volume of CNG due to the bottle arrangement, approximately 5 times the equivalent volume of Diesel [17]. The equivalent volume and weight of NG are calculated and plotted in figs 4 and 5. indicate the relative space demand and weight for the storage of LNG and CNG compared to that of the diesel fuel.

CNG bottles are manufactured by many makers around the world, with different capacity and weight. The available bottles sizes are not meet the required quantity of gas, therefore, the bottles are connected in package named, bottles battery.

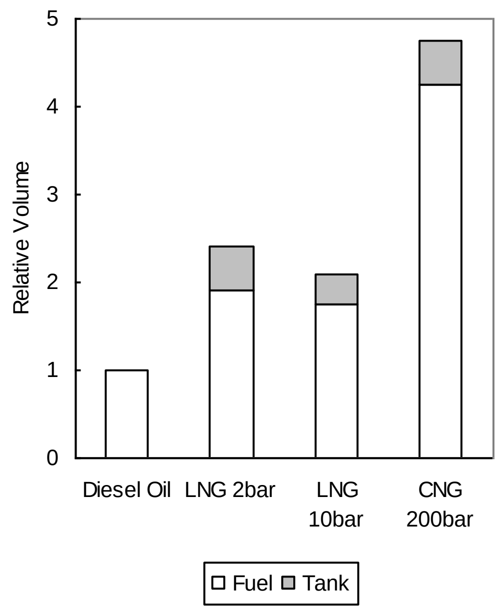

Fig. 4. Relative space demand fop the storage of NG compared to that of DO.

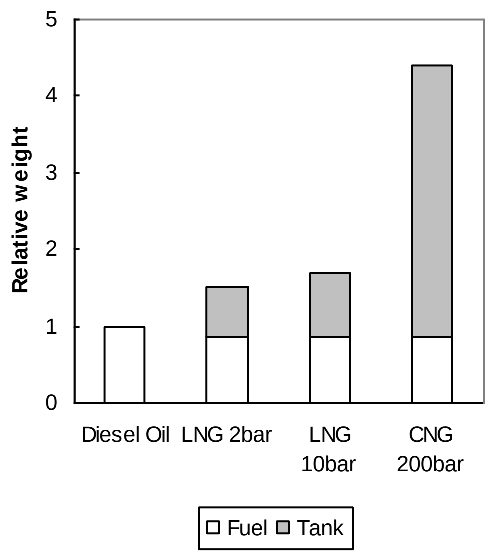

Fig. 5. Relative weight demand for the storage of NG compared to that of DO.

Egyptian petroleum sector establishes a basic framework for the design and manufacture of CNG bottles serving the road transport vehicles operating on gaseous fuels. The bottles dimensions are vary from 18 to 21.5 cm in diameters and from 124 to 154 cm in length. The national bottles weight and capacity are tabulated in table 3.

5.2. Liquefied nature gas onboard storage

The NG fuel for the inland water transport vehicles is preferred to store in a liquid form (LNG), owing to its lower weight and space demand compared to CNG, as shown in figs. 4 and 5. The LNG tanks are located and stored in designated tank room with special features. LNG must be maintained cold to at least -50°C to remain a liquid, independently of pressure. To full fill that requirement the LNG is stored at -190°C as 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 [18].

The tanks are of double-wall construction, efficiently insulated and vacuum-jacketed; available in marine specification Stainless Steel and rated to A60. The standard of the shelf tank geometry is of cylindrical format with domed ends and will typically sustain pressures from 0.3 to 17 bars. Most units can be stored aboard vertically, strapped on to a saddle. Table 4 indicates the capacity, pressure and dimensions of IMO-7 LNG inter model containers [19].

The LNG vapor boil-off produced during changes of state must be removed from the tank to allow the temperature to remain constant. The internal pressure and temperature inside the tank will rise if the vapor is not drawn off. In the recent fuel system the boil off vapor is fed forward to the fuel piping system to be used in propulsion or auxiliary machinery [20].

6. NG infrastructure issues

There are some issues that need to be addressed before generalize the applications of NG as fuel option for inland water transportations vehicles. These issues may be divided into three groups. The first will be the availability, handling and storage of NG. The second is the economical issue, and the third is the national legislations and regulations of NG operation.

6.1. NG net work and refueling stations issue

Although, the NG distribution infrastructure is expanded along the Lower Egypt and becomes a common fuel on most of the cities, the availability of NG is limited along the river Nile from Geza to Aswan, owing to the lake of infrastructure of the refueling stations in Upper Egypt. Currently, there are only a few sources of NG close to the water way barking area with bunkering capability.

The simple and temporary solution, for near future, is to introduce a small LNG or CNG carriers with a cargo capacity of a few thousand cubic meters to distribute the gas from the nearest available terminals in Giza to the vehicles or local storage tanks in the vessels parking locations along the waterway.
The permanent and best solution for the long run application is to extend the NG network pipe line to Upper Egypt and build small liquefaction plants for pipeline or CNG filling stations along the waterway, especially near by the parking area of the transportation units.

Table 3
The national specifications of CNG bottles

Cylinder size, m^3	13	14	15	16	17	18	19	20	21	22	23
Average weight, kg	57	62	66	70	73	78	84	88	92	95	98

Table 4
Specifications of the LNG containers

Model	Capacity liters	Pressure bar	Width m	Length m	Weight kg
TVS-52-250	19950	17.2	2.438	6.058	9980
TVS-53-150	20250	10.3	2.438	6.058	7850
TVS-54-60	20480	4.14	2.438	6.058	6030

The first class Cairo/Alexandria waterway through Nobaria canal extended up to 222 km and has 6 locks. The main first class waterway is Cairo/Aswan of about 980 km in length and has 4 locks. The lock has a cycle time of 45 min for each vehicle. Cycle time includes open/close time of gates, water filling/discharge time and enter/leave time of unit [3, 4].

The proposed parking area and refueling stations should be closer to locks places along the waterway to save time. The locks places is already stopping location for the inland water vehicles, waiting to the passing time through the lock. There are 4 locks from Giza to Aswan. The distance between both locations (980 km) may be divided into two main parts. The midpoint is located at Asyut lock far away from the starting point at Giza by about 415 km and from Aswan by 546 km. In additional, one refueling station will be located at the starting point at Giza and the ending point at Aswan. See the Upper Egypt map in fig. 6.

The map gives the gas refueling stations along Cairo/Aswan only. Since the Alexandria/Cairo waterway is short, 222 km, therefore, only one gas station will be located at the starting and ending points.

According to the inland vehicle specifications and the trip duration, the NG fuel could be estimated. The required amount of fuel decides the location and number of refueling. One m^3 of DO is equivalent to 2 m^3 of LNG and 4.2 m^3 of CNG, see fig. 4.

6.2. National legislations and regulations issue

A special national rules and regulations for gas fuelled ships should be issued. The first classification rules have recently been released by Egyptian traffic authorities for road transportation vehicles. The feasibility of gas use could be further boosted if emission trading and environmental impacts are introduced in inland water transport.

6.3. Economical issue

The price of natural gas operation is also an issue that needs to be evaluated before the introduction of new inland water vehicles.

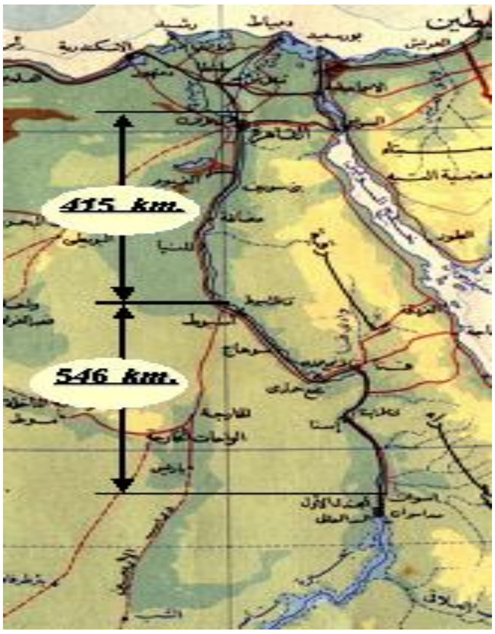

Fig. 6. The Upper Egypt map.

According to the calculations for the proposed NG fueled self propelled barge, the first cost of the barge will be higher than that of a conventional one owing to the complexity of the special gas arrangements and the high cost of the propulsion system.

However, the cost advantage favors the NG vehicle when compared against an environmentally sound conventional vessel burning high quality fuel such as MDO. Since the NG vessel offers the lowest emissions, the choice of fuel for the environmentally conscious operator is leaning towards NG. The national authorities should encourage the ship owners to apply the NG as fuel for their units by reducing the taxes and insurance interest. Also the encouragement will be sound by reducing the cost of NG (0.45 LE/m^3) compared to DO (0.6 LE/lit) cost.

National or company specific emission reduction goals could be achieved by introducing gas fuelled inland water vehicles instead of applying more costly measures to reduce emissions from land based operations.

7. NG engine selection and machinery arrangement

The inland water vehicles operation is intrinsically part of a wider transport network and has to accommodate present and projected levels of service, reliability, economy, traveling comfort, speed, safety and environmental friendliness. The use of an alternative fuel and power plant on the inland transport vehicle generates repercussions throughout, namely on safety, layout and structure. The use of NG as the primary fuel yields cleaner lubricating oil and reduced engine wear. This implies 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. All the advantages of the gases fuel and its friendship with the environment attracts the main engine com panies to carry and develop a lot of research aiming to optimize their products of gas engines for specific applications, inclusive of marine propulsion [21]. Fig. 7 lists the options in NG engine makers and the available power range of each company.

7.1. Gas/electric arrangement

Fundamental to the design of a main propulsion plant is the coordination of the prime mover with a transmission system and the propulsor. The ideal arrangement and installation of gas engines onboard inland barge may be carried as the following scenario:

The NG engine runs an electricity generator which powers an electric motor connected to the propeller shaft propulsion. This arrangement is initially more expensive and it is heavier than a mechanical drive.

The system merits include: Ease of control, providing excellent maneuvering capability. Ability to operate economically for lengthy periods at reduced speed/power. No mechanical links between power plant and propulsor, generator set can be placed to best compensate the vessels trim. The system offer low emissions and good economy within their designated range. The fixed speed gas/electric drive provides the best compromise in adapting the existing crop of gas engines to marine propulsion, at present.

A typical heat balance calculations for gas/ electric generator set is illustrated in table 5.

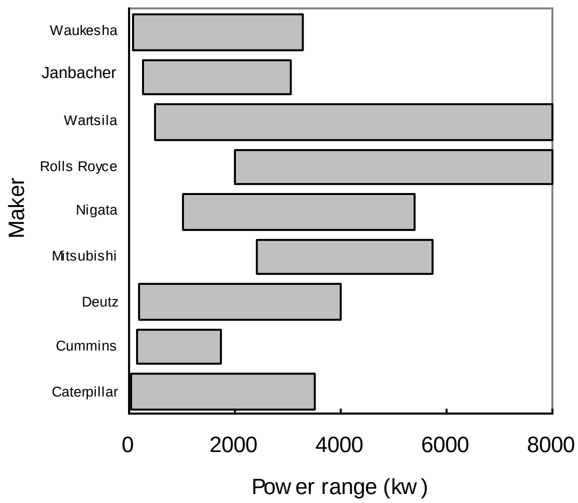

Fig. 7. Options of NG engine makers with various power ranges.

Table 5
Typical heat balance of gas/ electric arrangement

Items	Percentage
Shaft power	42.9
Exhaust gas	35.5
Jacket water cooling	7.0
Charge air cooling	5.6
Lub. Oil cooling	5.0
Radiation losses	2.5
Alternator loss	1.5

8. Conclusions

- The development and improvement of IWT should be associated with wider regulations to protect the environment along the waterway. The successful can be gained by using the national NG fuel and enhancing the national economy.
- The eagerness of authorities, regulatory bodies, private sectors and operators will add to the final impulse regarding how quickly NG can be put to work in IWT.
- NG has great public appeal and it is cheaper than diesel oil and price will lower with increase of supply. Also, NG is well established in the national urban transport and that technology can transfer in sympathy to water vehicles via availability of engines, safe storage systems and technical assistance.
- The reduction values of CO_x emissions can not be achieved when burning any other oil based fuels. Also the lack of particulates in NG

fuel eliminates 50% of PM emissions, while the clean burning properties of a lean burn gas engine reduce the NO_x emissions to a fraction of those produced by a conventional diesel engine.

• NG is a promising fuel, environmental friendly and improving the national economy.

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