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Design of a Low Emissions Harbour Tug

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SYNOPSIS

Crowley Maritime Corporation has designed a next generation solution for a very low emissions ship assist tug for service in Los Angeles and Long Beach (LA/LB) harbours. The tug will substantially reduce both US Environmental Protection Agency (US EPA) regulated emissions and currently unregulated greenhouse gas emissions over conventionally powered tugs in similar service. The vessel will be more powerful than any tugs now operating in the harbour, positioning it well for current and future service. The tug will also set new standards with respect to other shipboard emissions. Finally, the design considers issues of crew habitability such as safety, noise, and comfort.

INTRODUCTION

Crowley Maritime Corporation provides diversified domestic and international transportation and logistics services through its various business units. These business units provide container shipping, logistics, energy support, government services, petroleum and chemical transportation, contract towing and transportation, ship assist and escort, salvage and emergency response, vessel management, and vessel design and construction. Crowley has a company-wide environmental initiative aimed at reducing emissions and energy usage through improved energy efficiency. The company was recently recognised by the Chamber of Shipping of America for continued focus on environmental preservation and protection.

The Glosten Associates is a full service consulting firm of naval architects, marine engineers and ocean engineers, in business since 1958. Design experience includes tugs, barges, research vessels, ferries and marine construction equipment. With strong analysis and risk assessment capabilities, Glosten has been instrumental in developing tug escort requirements and analysing escort practices for tankers around the world. Glosten has developed software for ship stability, ship and tug manoeuvring simulation, and the management of ballast water uptake and release with respect to environmental regulations. Glosten is actively involved in many projects to reduce all types of shipboard emissions in vessels of all sizes and services.

Diesel-fuelled ship assist tugboats are contributors to marine emissions in and around major ports. As the international shipping trade increases steadily over the coming decades, diesel fuelled marine vessels will continue to generate nitrogen oxides (NOx), sulphur oxides (SOx) and particulate matter (PM), which have been factors in the non-attainment of National Ambient Air Quality Standards for some coastal communities in the United States. The shipping industry is also responsible for the emissions of greenhouse gases such as CO_2 that are contributing to global warming.

Operators, environmental groups and regulatory agencies are all interested in finding solutions for reducing vessel emissions. The US EPA has an established programme for the stepwise reduction of emissions from medium and high speed marine diesel engines. However, the viability of other options must be explored to ensure that the long-term increase in marine traffic will not be associated with increased emissions.

This paper presents some of the details for the design of a 72.5 tonne bollard pull, natural gas fuelled ship assist tug. The design concept is viable for operation in the LA/LB harbours and would reduce critical emissions to a level well below current regulations. The design will also significantly lower CO_2 emissions. Implementing the natural gas propulsion concept, along with other design practices described here, would result in significant improvement of harbour tug environmental performance.

Crowley Maritime provided overall leadership and guidance for the project with the Glosten Associates assisting with the design. Rolls Royce, as the equipment supplier, provided engineering support, while Hamworthy Gas Systems provided engineering for the gas storage and gas supply system.

DESIGN BASIS

As a major operator of ship assist tugs in the LA/LB harbours in Southern California, Crowley understands the special requirements of their tugs and the needs of the operators. Crowley is also very concerned about the potential impacts of emissions from their vessels. The following constraints and requirements formed the basis for this design.

The primary fuel shall be natural gas:

Natural gas, which is primarily made up of methane, contains the lowest amount of carbon of any hydrocarbon and therefore produces less carbon dioxide when combusted. Natural gas contains no sulphur, and when combusted produces much less Particulate Matter (PM) and Nitrogen Oxides (NOx) than distillate fuels.

Safe to operate:

Safety is Crowley's number one core value. Proper operation with natural gas is at least as safe as conventional diesel. Det Norske Veritas (DNV) has extensive experience in the classification of natural gas fuelled vessels in Norway and has been involved with this project from the beginning. DNV has written comprehensive rules for designing natural gas vessels[1] which have been used in the design of this tug.

At least 72.5 tonne bollard pull:

Tug operation in the LA/LB harbours requires assisting vessels up to 304,814 deadweight tonnes (DWT) which is the limit of the current regulatory force matrix. It is difficult to predict the required power of a future assist tug, but Crowley foresees needing a tug with a bollard pull of at least 72.5 tonnes.

Handy Size:

Operators expressed a preference for a 'handy'-sized tug for manoeuvring in some of the tighter berths. Therefore, the tug is to have a maximum length of 27.5m. For clearance under the Commodore Heim Bridge, the tug has an air draft limit of 12.2m. Additionally, the vessel is to be less than 300 Domestic Gross Register Tons (GRT).

Live Aboard Accommodation:

The tug must have accommodation for four crew members. The accommodation must maximise the privacy and comfort of the crew. Transmission of engine noise must be kept at a minimum.

Propulsion:

Propellers are to be Azimuthing Thrusters (Z-drives).

LOAD PROFILE ANALYSIS

In order to minimise emissions it was necessary to understand the loads the vessel may see in service and understand the way the vessel will operate. Engine load data was downloaded from Crowley's existing LA/LB harbour tug fleet from the engine's computers. Each engine has a computer that records and stores data on engine load and engine hours over its lifetime. The data from all the tugs was averaged and processed into a standard load profile (see *Figure 1*). This profile was used for fuel consumption and emissions calculations. Additionally, Crowley wished to understand the amount of time dedicated to various operations. Data was logged on several of the LA/LB tugs over a period of time and historical data from log books was also consulted. A descriptive summary of this data is shown in *Table 1*.

Operational Event	Approximate Percentage of Total Time
Standby/Loitering	6%
Ship Assist	28%
In Transit	17%
At Dock	49%

Table 1 - Operational Summary.

There follows a brief description of each operational event for a typical tug:

Standby/Loitering:

The tug is loitering at the breakwater for the ship to come into the harbour or waiting near the vessel's berth for the ship to untie. This operation nearly always precedes a ship assist. The tug's engines are at idle but occasionally the operator will adjust the position of the vessel. A small generator is providing power for hotel and auxiliaries.

Ship Assist:

The tug is assisting with the manoeuvring of the ship. The loads on the engines can fluctuate rapidly. A typical operation in LA/LB will require brief bursts of high power followed by periods of lower loads. This pattern is repeated throughout the ship assist operation. A small generator is providing power for hotel and auxiliaries.

In Transit:

The tug is transiting to or from a ship assist job. Crowley tugs work in both Los Angeles and Long Beach harbours. The harbours for each city are joined, forming a unified port complex. Transit times are short, averaging less than 30 minutes. Since most transit is in protected waters, the transit speeds and engine power levels are low. A small generator is providing power for hotel and auxiliaries.

At Dock:

The tug is tied up at one of the two Crowley docks in the harbour. The main engines are off and a small generator is providing power for hotel and auxiliaries.

Figure 1 shows how the engines are typically loaded over time. 90 per cent of the time the engines are operating under 50 per cent load and 98 per cent of the time they operate under 75 per cent load. The engines are sometimes fully loaded but only for a very small percentage of the time.

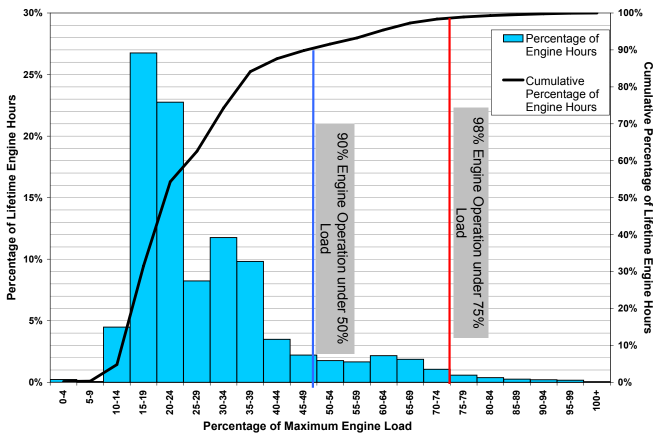

Figure 1: Percentage and cumulative percentage of lifetime engine hours spent at various engine loads.

Specific emissions (engine emissions/kW) are typically higher at lower engine loads. Since the tugboat is spending most of the time at lower engine loads, the specific emissions should be as low as possible. Lean burn gas engines have extremely low specific emissions. For NOx, the specific emissions for the engines are actually lower at low engine loads which is the reverse trend of most engines.

LEAN BURN NATURAL GAS ENGINES

Crowley has chosen to use Rolls Royce lean burn spark ignited gas engines to power the propellers. The engines run on natural gas fuel, which is readily available in the LA/LB area and is less expensive per unit of available energy than ULSD. Since the fuel contains no sulphur, the SOx emissions are essentially zero. The fuel is almost pure methane and as a result the emissions of particulates are nearly zero as well. NOx emissions are reduced by about 90 per cent and CO_2 emissions are also reduced significantly due to the very low carbon content of methane.

GENERATOR SETS

The electricity for auxiliaries and hotel as well as for the electric winch will be provided by a pair of small generator sets fuelled by ultra low sulphur diesel (ULSD). The generator set will be used whenever the vessel is operating and not at the dock. Since the vessel will spend nearly half the time tied up at the dock it was decided that it would be most efficient and produce the least emissions if the vessel plugged in to shore power whenever at the dock. Although the emissions from a small diesel generator are small compared with the mains, the cumulative effect cannot be dismissed since electricity is needed 24 hours a day.

DESIGN APPROACH AND CLASS REQUIREMENTS

The vessel will be fuelled by natural gas and be classed by DNV. DNV has written the only current set of comprehensive rules for classification of small gas fuelled vessels[1]. Work is currently underway at the International Maritime Organization (IMO) to develop a similar set of rules that could eventually lead to wider adoption by other classification societies and flag states.

The DNV rules were developed to ensure the safe design and operation of a natural gas fuelled vessel. The rules have been widely applied to a number of small and medium sized ships, primarily in Norway where natural gas is readily available. Below is a list of DNV classed vessels that are built, under construction, or under contract to be built.

- 300-passenger, 96-vehicle ferry ***Glutra***, delivered 2000, Norway (this was the first ferry classed under the rules);
- Two platform supply vessels, 6,000DWT, delivered 2003, Norway;
- Small coastal LNG carrier, combination gas and diesel, delivered 2004, Norway;
- Five 590-passenger, 212-vehicle ferries, Rolls Royce Bergen gas generator sets, delivered 2007, Norway;
- Three Norwegian Coast Guard vessels, combination gas/diesel, delivery beginning March 2008, Norway;
- Two platform supply vessels, expected deliveries in 2008 and 2009, Norway;
- Three 590-passenger, 212-vehicle ferries, Rolls Royce Bergen generator sets, contracted, Norway;
- 600-passenger ferry, contracted, Norway;
- 463 passenger, 74 vehicle, high speed ferry, contracted, Brazil.

Two design philosophies are possible under the DNV rules:

1. Inherently safe: The arrangements in machinery spaces are such that the spaces are considered gas safe under all conditions, normal as well as abnormal. In this approach, all gas piping is enclosed in ducts or double-walled pipes in the engine room. The annular space is either filled with inert gas of a higher pressure than the gas within the center pipe, or ventilated to 30 air changes per hour with gas detection in the outer duct.

2. Emergency Shut Down: Spaces with gas piping are considered non-hazardous under normal conditions, but under certain abnormal conditions may have the potential to become gas hazardous. In the event of abnormal conditions involving gas hazards, emergency shutdown (ESD) of non-safe equipment (ignition sources) and machinery shall automatically occur. Additionally, equipment in use during these conditions shall be of explosion-proof design. Therefore, the ESD philosophy requires a second engine room to maintain operations if one should be shut down.

A second engine room in a vessel of this size is not practical so the ESD approach was not considered. Therefore, this vessel is designed around the 'inherently safe' philosophy.

DNV requires that an independent fuel supply be installed for both approaches. A design with only natural gas engines requires the vessel to have two independent gas fuel systems (two tanks, two delivery systems etc). A second possible approach is dual fuel engines that run on both diesel and natural gas. A third option is to have a combination of gas-fuelled and diesel-fuelled engines.

Tank and gas piping location and design is also carefully governed within the rules. At minimum, the tanks are required to be the lesser of 1/5 the beam or 11m from the ship's side, and the lesser of 1/15 the beam or 2m from the bottom plating. The tank or gas piping shall never be less than 760mm from the shell plating. Tanks stored below the main deck are also limited to a working pressure of 10 bar.

Many other robust and redundant safety measures are dictated by the DNV class requirements and give a high degree of safety. In aggregate, these rules act to drive the general and machinery arrangement in ways not typically seen in conventionally fuelled vessels, presenting unique challenges for a vessel such as a harbour tug.

GAS FUEL SYSTEM

The gas fuel system consists of liquid storage tanks, a vaporiser (cold box), a gas valve unit, piping and a bunkering system.

STORAGE TANKS

The natural gas is stored as a cryogenic liquid in vacuum insulated, low pressure tanks that will be supplied by Hamworthy Gas Systems of Norway. The tanks are double-walled austenitic steel with the outer wall acting as a secondary barrier to contain a leak and contain pressure if the inner tank was breached. The tanks operate at approximately 4 bar. Boil off from ambient heat can cause pressure to build in the tank. The tanks have a relief valve set to 10 bar to prevent over pressurisation. Should it be necessary to relieve pressure in the tank, the gas is routed out of the tank and away from the vessel via the 'gas mast'. DNV regulations govern the location, height, and arrangements of the 'gas mast' to prevent the possibility of gas being vented near potential sources of ignition. These types of tanks have a proven marine safety record and have been installed on about a dozen vessels since 2000, all certified by DNV.

TANK ROOM

The natural gas is delivered to the engines as a gas but stored as a liquid. A 'tank room' is physically attached to each storage tank and contains the equipment to convert the liquid into a gas for safe delivery to the engines. The tank room consists of two heat exchangers and a master gas valve. One heat exchanger is used to build up pressure within the tank to the required level to allow fuel to be delivered to the engines. The other heat exchanger is used to vaporise liquid fuel and heat it up to the temperature required for delivery to the engines. Heat from the engine cooling water can be used as a heat source for vaporising the gas.

The tank room is also considered a 'secondary barrier' since liquid pipes are inside it. The secondary barrier is required by DNV for leak containment and detection. The tank room is equipped with leak detectors and is ventilated with 30 air changes per hour.

GAS REGULATING VALVE ASSEMBLY (GRV) GAS PIPING

The Gas Regulating Valve Assembly (GRV) is installed in a separate ventilated compartment as close to the engines as possible and ventilated with 30 air changes per hour. The piping between the tank room and the GRV is double-walled as is the piping between the GRV and the engine per the 'inherently safe' requirements.

The GRV performs the following functions:

- controls the pressure level of the fuel gas delivered to the engines;
- regulates the flow of gas to the engines by
  (i) stopping the flow of gas when the engine is shut off
  (ii) bleeding off residual gas in the line through the double 'block and bleed valves';
- automatically performs a leakage test of the block valves when the engine starts to ensure safe operation.

BUNKERING OF FUEL

The bunker station is located outside the machinery space in a well-ventilated area and must be equipped with a gas detection system according to DNV rules. The manifold has a pressure gauge, a manually operated stop valve, and a remote operated shutdown valve. A drip tray beneath the bunkering station will be made of austenitic steel. Liquid fuel, if necessary, can also be transferred back into a tank truck from the on-board storage tanks. After fuelling, the bunkering lines are gas freed and filled with inert gas (nitrogen).

MACHINERY ARRANGEMENTS

The arrangement of equipment in this vessel was a significant challenge. Major equipment is listed below:

- Two thrusters (Rolls Royce US 255 CP Z-Drives);
- Two propulsion engines (2,600kW each, 1,000 rev/min, Rolls Royce KVMS-12G4 lean burn spark ignited gas engines);
- Two diesel generator sets (99kW each);
- One ship service/auxiliary switchboard;
- Two liquefied natural gas storage tanks (21m^3 each);
- One gasification and heating unit;
- One GRV enclosure (with two GRVs).

Space and weight limitations create a unique design challenge for locating large liquefied natural gas tanks as well as large, medium speed engines on a tug of this size. Because the tug will operate in a harbour system where fuel is readily available, large fuel capacity is not required since the vessel can bunker while at the dock from a tanker truck.

The engine room is located amidships and contains the two propulsion engines and the diesel generator sets and switchgear as well as other auxiliary equipment. Forward of the engine room is the tank storage room that contains the two natural gas tanks oriented horizontally with the tank rooms located on the outboard side of the tanks. Forward of the tank storage room is a small storage space for the ship's supplies. The thruster room is separated from the engine room by a water-tight bulkhead.

DNV classification requires two gas storage tanks and gas delivery systems when gas is the only propulsion fuel

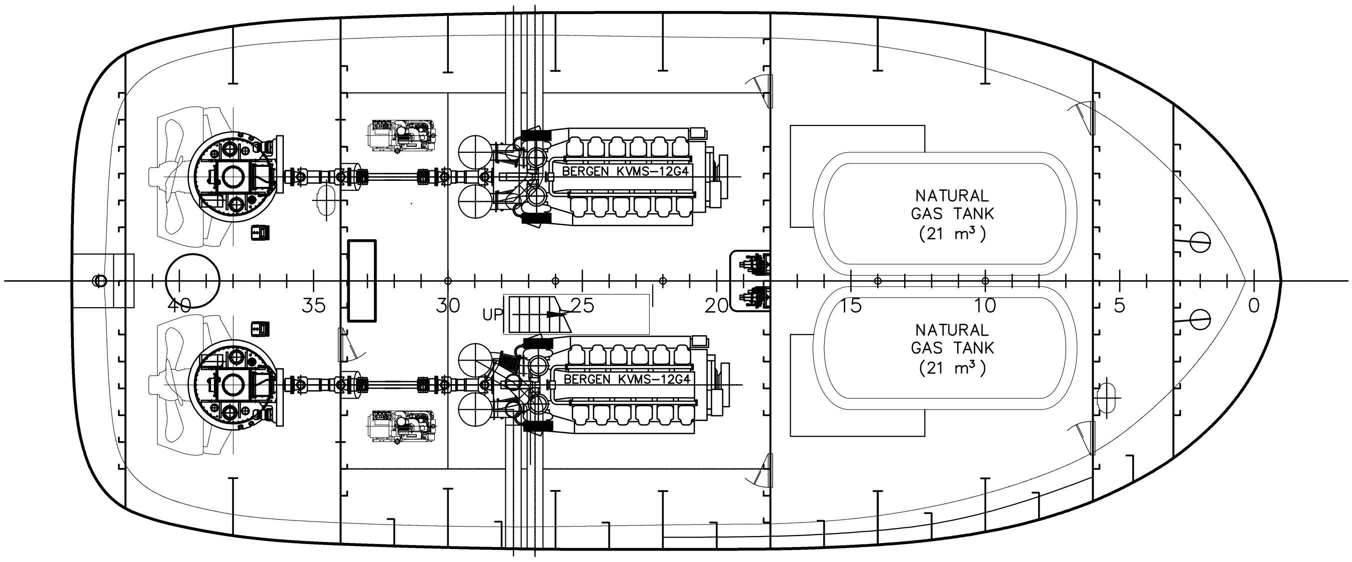

Figure 2: Machinery arrangement.

on board. The tank capacity allows for a minimum of five days' fuel supply under average operating conditions. This bunkering cycle was considered a reasonable trade-off to the added volume of larger tanks.

The exhaust system for this vessel is also unconventional. Since most of the exhaust emissions are virtually eliminated, and since exhaust pipes are typically an impediment to good bridge visibility, the exhaust from the engines is first run through a silencer, then cooled with seawater and run outboard above the waterline. During some operations the pipes could become submerged or blocked. A relief valve allows the exhaust to be discharged just after the silencers if the backpressure should be too high, but still well below the level of the pilothouse. This arrangement will greatly enhance bridge visibility.

GENERAL ARRANGEMENTS

Crew safety and comfort are of paramount importance. Even at 27.5m, each crew member will have their own stateroom. The vessel has one deck head/shower and one head/shower that is shared between the two port staterooms for the captain and engineer. Two of the staterooms are outfitted for double occupancy, to allow for occasional trainees or supernumeraries. A combined mess and lounge has been placed aft of the accommodation as well as a separate galley. These spaces are separated from the accommodation block by the head and locker to reduce noise carrying forward to the quiet spaces. Finally, to further limit noise transmission, the crew area is isolated from the machinery space by a floating floor.

A summary of the vessel details is shown in *Table 2*.

General Characteristics	
Length Over All	27.5 m
Beam	12.2 m
Draft	4.6 m
Displacement	634 tonnes SW
Domestic Gross Register Tonnage	Under 300 GRT
Minimum Bollard Pull	72.5 tonnes
Air Draft	11 m (with mast down)
Azimuthing Thrusters	(2) Rolls Royce US 255 CP
Natural Gas Engines	(2) Rolls Royce KVMS-12G4, 1,000 rpm
Deck Equipment	
Bow	Render-Recover winch
Stern	Capstan
Electrical System	
Generator Sets	(2) 99 kW
Ship Service Electrical	480/208/120 VAC
Fuel System	
Propulsion Fuel	Natural Gas
Generator Fuel	Ultra Low Sulphur Diesel
Liquefied Natural Gas Capacity	42 m^3
Diesel Capacity	7,500 litres
Refueling Cycle – Natural Gas	5 days
Other	
Crew	4 persons
Crew State Rooms	2 Double, 2 single
Water Treatment System	Closed cycle, no overboard emissions

Table 2: Design details.

EMISSIONS

An analysis was performed to estimate the approximate reductions in emissions for the natural gas tug as compared to a conventionally powered tug of identical size and in identical service.

The conventional tug is powered by two EPA certified Tier 2 engines fuelled with ultra low sulphur diesel (15ppm sulphur). The same hotel loads and auxiliary loads were applied to both vessels. Both vessels are assumed to operate with the same load profile.

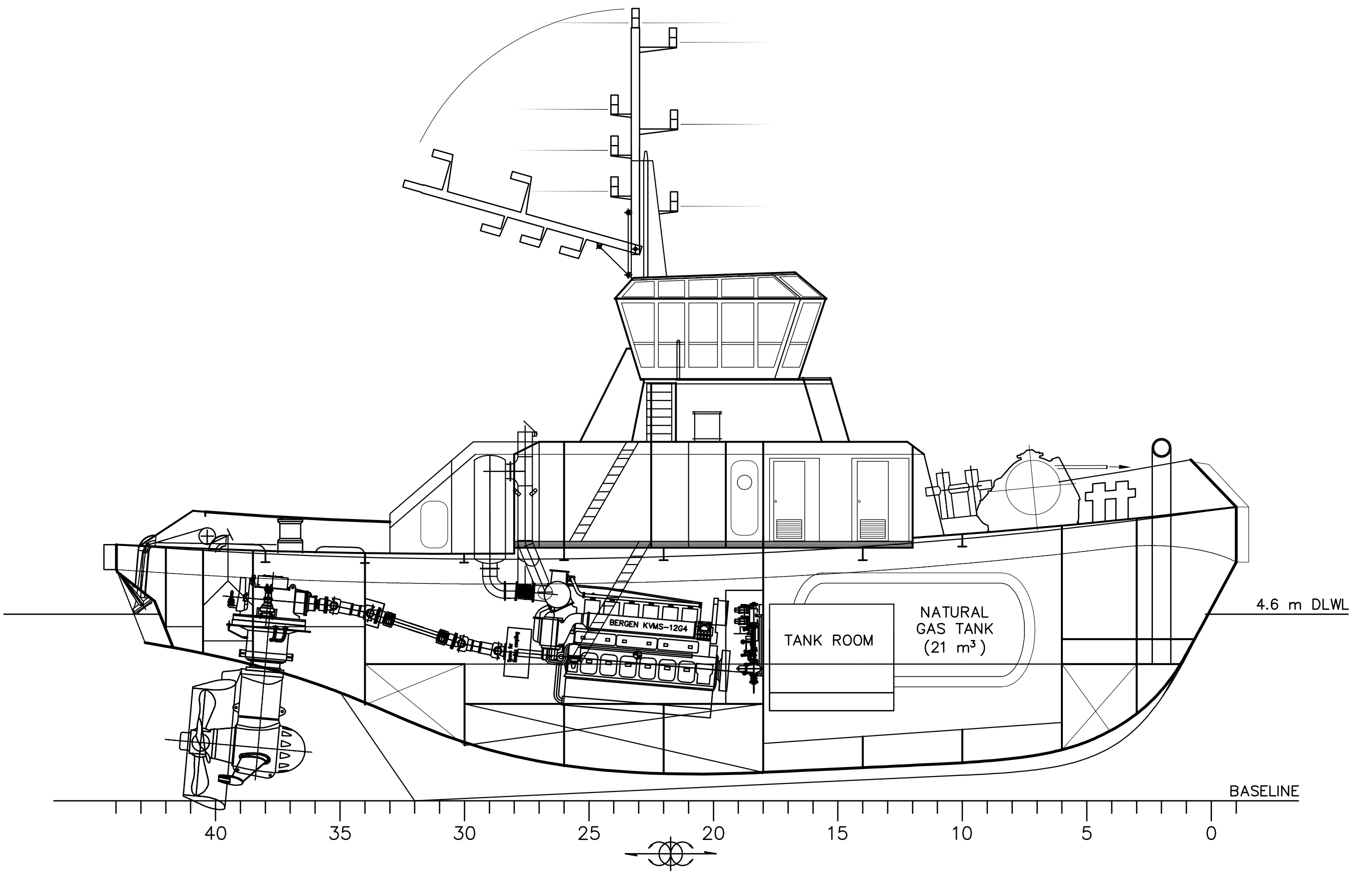

Figure 3: Inboard profile.

Emittant	Emissions Reduction using Natural Gas Fuel
NO_x (Oxides of Nitrogen)	89%
PM (Particulate Matter)	90%
SO_2 (Sulphur Dioxide)	94%
CO_2 (Carbon Dioxide)	24%

Table 3: Estimated emissions reductions for natural gas tug vs conventionally-powered tug.

OTHER CLEAN DESIGN FEATURES

Crowley is also considering other ways to reduce the environmental impact of this harbour tug. The tug will be equipped with a sewage treatment system that produces no overboard emissions and no sludge. The fresh water system is able to treat and recycle all waste water for flushing without odour or colour. Some water will evaporate and need replacement but none will be discharged.

The lighting will be designed to maximise efficiency and crew comfort. All motors used will be 'premium efficiency.' Environmental considerations will also be made for the type of materials used in the construction of the vessel such as paint, steel, flooring, and joinery work.

CONCLUSION

This vessel will advance the state of the art for environmental performance of a harbour assist tug by significantly reducing the engine emissions that are currently of greatest concern in populated areas, such as NOx, SOx, and PM, while also cutting CO_2 emissions by a quarter. Although Crowley considers this vessel to be an important step, it will continue to innovate and look for opportunities to improve efficiency and reduce the environmental footprint of all of their operations.

REFERENCES

[1] Det Norske Veritas, *Rules for Classification of Ships*, Newbuildings, Special Equipment and Systems Additional Class, Part 6, Chapter 13, Gas Fuelled Engine Installations.