

# World's First LNG Dual-fuel Engine Adapted for High-Speed Vessels

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**Abstract:** As of 2020, shipping companies will have to use low-sulphur fuels to comply with current international regulations set out in Annex VI of the MARPOL Agreement (regulations for the prevention of air pollution from ships), which will limit the maximum sulphur content in marine fuels to 0.5%. It is against this backdrop that natural gas (LNG) is being considered as one of the primary alternative fuels to enable compliance with this international regulation. Currently, there are 103 LNG-fuelled vessels in operation around the world and 97 on order. Car and passenger vessels make up the largest segment, accounting for 40 of the 103; none of these, however, is a high-speed (HSC) ropax vessel with capacity for both passengers and trucks in open seas. HSC vessels are deployed in niche markets requiring high-speed propulsion engines (around 1,000 rpm) that can maintain service speeds. Existing LNG dual-fuel engines cannot be used to retrofit HSC vessels as they have been developed from a range of medium-speed engines (around 500-700 rpm) and they are heavier than those high-speed engines traditionally used by the HSC industry. This paper presents the innovative technology developed for the world's first adaptation of a high-speed engine to LNG dual-fuel use by the shipping company Fred. Olsen S.A., within the GAINN4SHIP INNOVATION project.

**Key words:** LNG, dual-fuel engine, innovation, energy efficiency, maritime transport.

## 1. Introduction

The upcoming implementation of the international environmental regulation, MARPOL Annex VI, will force ship owners to assess different fuel options and technologies that enable them to comply with the regulation whilst helping them to improve their position in an increasingly competitive market. The forthcoming global 0.5% limit on sulphur in 2020 is driving ship owners to evaluate alternative fuels as a means for compliance.

Given the fragility of the European economy, prevailing uncertainty about its future and about the future evolution of key factors (such as fuels prices) affecting the outcome of ship owners' decisions, making the right choice among the multiple feasible technologies available becomes a considerable

challenge.

The shipping company Fred. Olsen S.A., which daily connects the Canary Islands using high-speed-vessels, has carried out a thorough analysis of three alternative solutions in order to decide which technology would best enable compliance with technical and environmental regulations.

- Using alternative fuel oil with a maximum sulphur content of 0.5%

Marine fuels are classified by ISO:8217 depending on their origin (residual or distillate), viscosity and carbon residue. The most common denominations to different qualities of the fuel are HFO (heavy fuel oil) for pure residuals; IFO (intermediate fuel oil) for mixtures of residuals and distillates and MDO (marine diesel fuel) and MGO (marine gas oil) for pure distillates. Fuels with residual content (HFO and IFO) are sold with different sulphur content levels, however, all of them have over 0.5% sulphur.

Heavily desulphurised IFO fuels could also be used,

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but in practice the desulphurisation of HFO is too expensive to make economic sense. A cheapest ULSFO (ultra-low-sulphur fuel oil) is commercially available, composed exclusively of distillates with a sulphur content of under 0.5%.

The vessels operated by Fred. Olsen S.A. run on MGO at 0.1% of sulphur content, which is significantly more expensive than HFO or LNG. In order to reduce operating cost it could be evaluated the use ULSFO, but these fuels are not compatible with high-speed engines used on high-speed ropax vessels. Therefore, there is currently no alternative fuel oil that Fred. Olsen S.A. can use in order to comply with the international regulation.

- Installing scrubbers on board the vessel

The use of HFO in combination with scrubber systems to remove the sulphur content from the vessel's exhaust gases seems to be an ideal solution. However, not all vessels are suitable for scrubbers.

This solution could not be used for HSC vessels as (1) HFO is not a fuel compatible with high-speed engines; and (2) the extra weight resulting from having this system on board would reduce the speed and payload.

- Using LNG as a marine fuel

Currently, LNG is the most environmentally-friendly and sustainable fuel: it emits practically zero sulphur, up to 85% less NO<sub>x</sub> and at least 20% less CO<sub>2</sub>. From an economic point of view, LNG costs on average approximately 35% less than MGO. In addition, LNG vessels benefit from a reduction in port taxes.

The main obstacles for using LNG as a marine fuel are the major investments required for replacing or adapting engines on the vessel and the lack of LNG bunkering facilities to supply LNG to shipping and port consumers.

The results of this analysis show that, from a technical, environmental and economic point of view, for the case of high-speed vessels, it is preferable to invest in LNG technological solutions.

Based on these conclusions and thanks to the

GAINN4SHIP INNOVATION project, coordinated by Fundación Valenciaport and co-financed by the European Union via the "Connecting Europe Facility" programme, Fred. Olsen S.A. will retrofit the HSC Bencomo Express vessel to run on LNG dual-fuel. The company intends to retrofit not only this vessel but also its entire fleet in the short-to-medium term, thereby maintaining its current high-speed-vessel shipping model independent of future fuel prices.

## 2. How to Retrofit HSC Vessels to Run on LNG

Pioneering technology will be used for the HSC Bencomo Express retrofit as there is currently no technology available that could be implemented with HSC vessels. This is the first case in the world of an adaptation of an HSC ropax vessel to be powered by both diesel and LNG. The technical solution applied to the Bencomo Express will demonstrate the feasibility of using LNG as a marine fuel for these types of vessels.

All the different options that could be used to retrofit the HSC Bencomo Express to run on LNG have been thoroughly analysed and the results are summarised as follows:

- Powering the HSC Bencomo Express with LNG gas turbines

Although the first and only LNG-powered HSC in the world is the new build HSC Francisco operating between Argentina and Uruguay, the technology used to power it with LNG is entirely different from the technology to be used for the HSC Bencomo Express. The HSC Francisco is the first HSC powered by gas turbines using LNG as a primary fuel source and marine distillate for standby and ancillary use. In particular, the HSC Francisco is equipped with two 22MW GE LM2500 gas turbines driving two Wärtsilä LIX 1720 SR water jets. The vessel is designed to transport passengers and cars at 50 knots in a river with maximum SWH (significant wave height) of 2.5 m. The HSC Bencomo Express will be the first

LNG-fuelled HSC in the world transporting passengers, cars and cargo vehicles in open seas with up to 5 m SWH.

The high consumption of gas turbines (3 to 4 times the average diesel engine fuel consumption at the same nominal power), means that this solution is only profitable for the shipping companies operating in countries where they can buy LNG at extremely low prices, which is the case for the Argentinean market. This kind of solution would not be possible in Europe where LNG prices are considerably higher than in Argentina, and would be even less attractive in the Japanese market. The capital cost of just one 22 MW dual fuel turbine is above €10 m, while for a similar amount one could get four 9 MW diesel engines (36 MW) designed for HSC. Thus the investment becomes prohibitive.

Maintenance tasks (time between overhauls, TBO) on turbines are driven by the thermal cycles, directly related to the number of start-stop cycles of each turbine. With diesel engines, on the other hand, TBO depends on the engine running hours. Thus, when an HSC makes several port calls per day (several start-stop cycles), the maintenance cost is much higher using turbines. Considering the actual route of the HSC Bencomo Express, using dual-fuel turbines would mean adding an intermediate overhaul every year and having a major overhaul every two years. In comparison, with the present vessel engines an intermediate overhaul is needed every three years and a major overhaul every six years.

Gas turbines are not a suitable technological or economic solution for most HSC ropax services in Europe as the maintenance costs for this technology increase substantially in direct relation to the number of port calls in the vessel itinerary. Given that the average port-to-port transit time of the 67 high-speed shipping lines operating in the European Union is 4.5 hours, the vessels' average number of stops is very high and using gas turbines would make maintenance costs prohibitive.

- Installing new LNG engines on the HSC Bencomo Express

HSC vessels are deployed in niche markets requiring high-speed engines (in the 1,000 rpm range) for these maritime transport connections. Many high-speed short-sea services are currently offered to connect ultra-peripheral regions with the EU mainland or with outer islands, or between islands in remote archipelagos. Given the peripheral nature and lack of connectivity of many of the ports where these services operate, maintaining service speed is crucial to foster territorial cohesion and contribute to reducing peripherality. Losing speed is unacceptable to the sea carriers as speed is the most important feature of this kind of maritime transport service.

A lightweight craft is crucial in order to reach high-value commercial speeds. LNG has 50% of the energy density of diesel oil and therefore, roughly speaking, about four times the space is required for the LNG tanks, piping and other fuel-handling equipment. Together with the heavier LNG medium-speed engines (in the range of 500-700 rpm), this results in a propulsion package (for the same power range) that is significantly heavier than a conventional high-speed diesel engine installation.

Indeed, one set of conventional medium-speed LNG engines available in the market weighs approximately 200 tonnes more than one set of high-speed diesel engines installed on HSC vessels. In the case of the Bencomo Express it would mean losing a third of the carrying capacity of the vessel, this being unacceptable for a sea carrier. Thus, a solution to the LNG engines' extra weight must be found if HSC vessels are to be fuelled by LNG.

The installation of new commercially-available LNG or dual-fuel engines is not possible, as four out of the six existing new dual-fuel engines do not fit into the engine room. In the case of the two new dual-fuel engines that do fit into the engine room, the loss of carrying capacity would be 28.3%, which is unacceptably high. Losing such a high percentage of

carrying capacity would make the retrofitting investment financially unfeasible.

- Adapting the existing engines of the HSC Bencomo Express to LNG dual fuel

The only solution found to the challenge of applying existing technologies to HSC vessels is to adapt the engines currently on board to burn a blend of diesel and LNG, rather than replacing them with new ones. This solution will provide the best results in terms of environmental performance, regulatory compliance and technological and financial feasibility.

### 3. LNG Dual-fuel Adaptation for High-speed Marine Engine

As mentioned above, the only available option for retrofitting the HSC Bencomo Express to LNG dual-fuel is adapting her four Caterpillar 3618 (CAT3618) engines [1]. As there is no commercially-available technology to adapt these engines, Fred. Olsen S.A. has first developed the dual-fuel technology required.

Even though the technology used to retrofit stationary diesel engines to run on a blend of diesel and LNG is well established, this is the first adaptation of a high-power marine engine (7,200 kW). In addition, it has been important that the adaptation of the engines is not considered a “major conversion” according to the NOx Technical Code 2008 [2].

Fig. 1 summarises all the steps carried out to adapt the external second-hand sister engine (diesel CAT3618) to LNG dual-fuel use (FO3618DF): engine overhaul; design and building of the dual-fuel conversion kit; installation of the conversion kit; adaptation of the test bench at Navantia (Cartagena) to dual-fuel operations; and finally, the test of the adapted engine in order to achieve the certification of the dual-fuel engine (issued by the classification society DNV-GL) [3-5], which certifies the safe and reliable operation of the engine in dual-fuel mode.

In order to avoid the vessel spending along time in dry dock, and all the operational costs that this would entail, the technology developed was installed in an external second-hand sister engine with the same characteristics as the four engines on board the vessel. In addition, this option allows the test to be conducted in a controlled environment, improving the safety and increasing the number of parameters and scenarios tested.

Firstly, the external second-hand sister engine was dismantled and revised by the engine dealer, Finanzauto, in order to ensure the test bench did not produce incorrect results due to low engine performance.

Secondly, the conversion kit used to adapt the engine to dual-fuel was designed and built. The adaptation of the engine mainly consists of the injection of natural

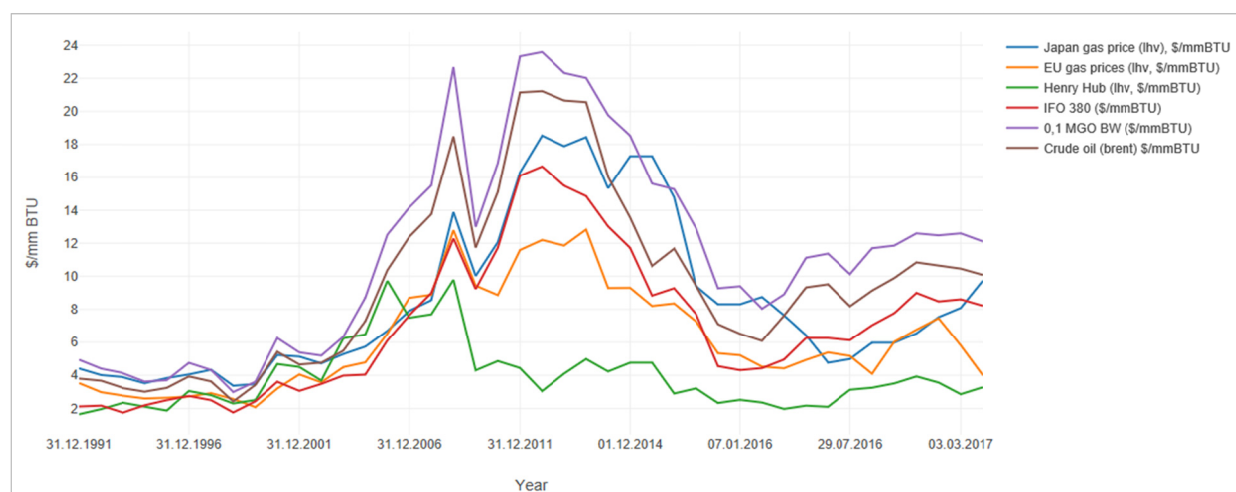


Fig. 1 Gas and oil prices.

Source: DNV-GL.

gas into the admission air, maintaining the initial diesel injection system. Consequently, this adaptation does not limit the unrestricted diesel operation, if required. The key to this adaptation has been the development of a cost-effective conversion kit that is easy to install on the CAT3618. The kit consists of several type-approved components in a double-walled configuration, meeting the requirements of “ESD (Emergency Shut Down) protected machinery spaces” according to the IGF Code (International Code of Safety for Ships using Gases or other Low-flashpoint Fuels). In particular, the dual-fuel system is operated by a control system that activates double-walled gas admission valves designed for marine applications. Additional systems such as an intelligent air path management and a Knock Control System are installed, making it possible for the engine to run with a replacement ratio of up to 90% natural gas/10%MGO.

A thermodynamic simulation running on dual fuel was carried out, as well as a transition simulation when switching from dual fuel to MGO and vice versa. This was done in order to optimise the conversion kit for these particular engines, determining consumption amounts and establishing the final test bench protocol required. After the thermodynamic simulation running on dual fuel, the conversion kit was built and installed following the design defined for future implementation on the four engines on board.

AVL List GmbH AVL, a company specialising in the development, simulation and testing technology of power trains systems, was responsible for optimising the conversion kit design, the thermodynamic engine modelling, real time dual-fuel engine modelling and the simulation. Heinzmann, a competent and innovative supplier of dual-fuel systems supplied the conversion kit for the adapted marine engine.

Through a public tendering process, Navantia was selected as subcontractor for conducting the test bench. The next step was to define the test bench layout required for the adapted engine to be tested in dual-fuel operation with LNG according to the DNV-GL rules

for Gas-Fuelled Ship Installations that entered into force in January 2016. The test bench was adapted to dual-fuel operations in accordance with the applicable legislation, in order to ensure its safe operation with natural gas by AVL Ibérica. A portable LNG station by Endesa was installed at Navantia facilities in Cartagena (Spain) in order to supply LNG to the test bench at the pressure and flow required.

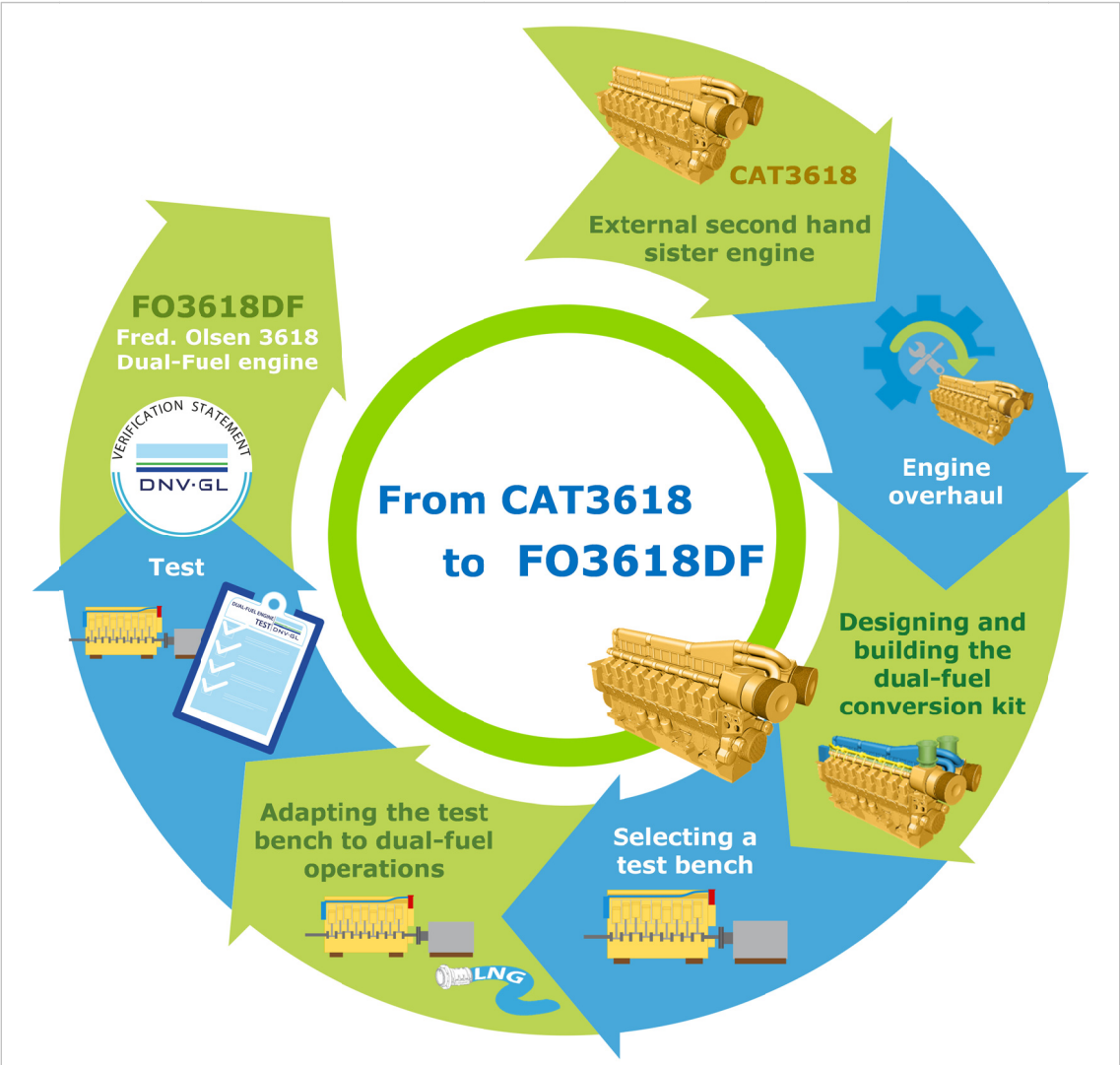
Finally, the tests to validate technical characteristics and emissions from the adapted engine (FO3618DF) were successfully completed by the end of November 2016.

The engine starts running on diesel before reaching the switching point at a certain load. The engine transition has been carefully analysed in order to ensure a quick, smooth switchover from diesel to gas and back again. In case of gas system failure, the engine immediately runs on diesel. Furthermore, the effect of the load change on the dual-fuel engine performance in bad weather conditions required special attention to assure smooth sailing and reliable engine operation.

In terms of emissions, the results of the test were better than expected. The emissions from the retrofitted engine show a 90% reduction in sulphur oxides as well as a 32% reduction in carbon dioxide and 45% in nitrogen oxides, when the engine is operating in dual-fuel mode with a ratio of 90% natural gas to 10% diesel [6-13].

AVL supervised and evaluated the emission and reliability test at the Navantia test bench in order to receive the certification issued by the classification society DNV-GL, which certifies the safe and reliable operation of the engine in dual-fuel mode. Measurements of exhaust gas emissions from the retrofitted engine were carried out with the collaboration of the UPCT (Polytechnic University of Cartagena).

In terms of engine performance, the normal operating conditions were simulated, demonstrating a noticeable reduction of fuel consumption due to the increase in engine efficiency. The situations tested



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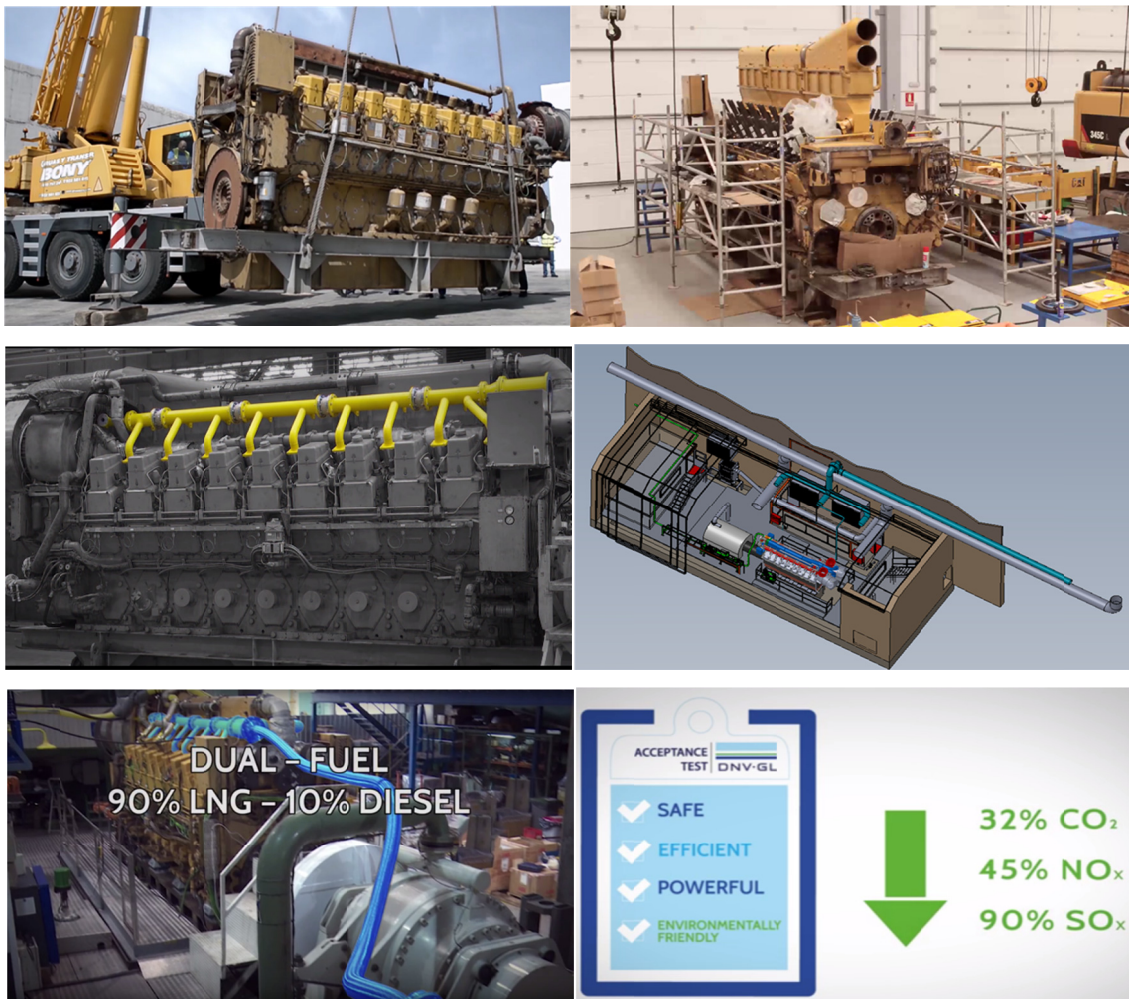


Fig. 2 Adaptation of a high-speed engine to dual-fuel operation [14-17].

Source: Fundación Valenciaport—Fred. Olsen S.A.

More detailed information: <https://www.youtube.com/watch?v=oLrFqA9eios>.

included sailing in adverse weather conditions, demonstrating high reliability in dual-fuel mode. The approval of the dual-fuel engine was completed on 28 November 2016.

#### 4. Conclusions

A thorough analysis has been carried out of technical options for designing much more environmentally-friendly high-speed vessels to meet the 2020 objectives and the international environmental regulation deadlines. The most promising solutions focus on the energy efficiency of the HSC by: (1) using existing LNG technologies applied to HSC (turbines); (2) using commercially-available medium speed LNG engines; and (3) retrofitting the existing engines on board to use LNG. Powering HSC vessels operating in Europe with LNG gas turbines is not possible as the capital cost is prohibitive, the maintenance cost is extremely high and the vessel's fuel consumption would also be very high. On the other hand, installing new medium speed LNG engines on the HSC Bencomo Express is not possible as four out of the six existing new engines do not fit into the engine room. In the case of the two new engines that do fit into the engine room, the loss of carrying capacity would be 28.3%, which is unacceptably high. Losing such a high percentage of carrying capacity would make the retrofitting investment financially unfeasible. Therefore, the only available option for retrofitting HSC vessels to LNG dual fuel is adapting the existing high-speed engines on board [18, 19].

As there is currently no technology available that could be implemented to retrofit HSC vessels to run on LNG, the company Fred. Olsen S.A. has carried out the adaptation of a high-speed propulsion diesel engine (CAT3618) to run on LNG dual-fuel mode (FO3618DF). The result is the world's first LNG dual-fuel engine adapted for high-speed vessels.

This internationally pioneering technology will be used to convert the four CAT3618 engines currently on

the high-speed vessel Bencomo Express, but it could be applicable to most high-speed vessels operating around the world.

LNG as marine fuel has proven to be cheaper and cleaner than existing conventional fuels: emissions from the retrofitted engine show a 90% reduction in sulphur oxides as well as a reduction in carbon dioxide and in nitrogen oxides, when the engine is operating in dual-fuel mode with a ratio of 90% natural gas to 10% diesel [20-27].

At this initial stage of implementation of LNG as marine fuel, this solution enables a significant reduction in capital expenditures, while maintaining the highest safety standards.

This initiative has been carried out by the shipping company Fred. Olsen S.A. thanks to the GAINN4SHIP INNOVATION project, co-financed by the European Union and coordinated by Fundación Valenciaport.

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