Alternative Fuels

General overview of the alternative fuels options in the marine sector

Yachting newbuilding market is making great strides in evaluating and testing alternative fuel solutions. These solutions range from the use of hydrogen and fuel cells to supply the vessel's electric load, to hybrid or electric propulsion for short navigation, to the use of LNG or methanol with reformers and fuel cells, or as part of dual fuel internal combustion engines.

Among them, we outline below the hydrogen and the methanol green options.

Hydrogen

Hydrogen is the most widely available molecule on the planet. It is carbon-free, energy-dense and its only byproduct is water. The use of hydrogen presents challenges, since its molecule is very tiny, increasing the chance of leakage. Its ability to ignite and explode, implies that safety must be paramount in design and operation. Another challenge is the difficulty and expenses associated with its storage. Studies have shown that hydrogen can either be stored at high pressure (compressed form), or at low pressure, using metal hydrides that absorbs hydrogen, or in liquid form at very low temperature (-253°C).

Methanol

Methanol also offers a viable alternative since it can reduce the carbon dioxide in emissions generated by marine diesel oil or marine gasoil, especially when bio-methanol is used. Methanol has the benefit of being liquid at room temperature and atmospheric pressure, being sulphur-free, and having low overall emissions. So while it has its limitations, methanol is easier to handle and has higher energy density than hydrogen. Both methanol and hydrogen have a low flash point, which must be addressed both by applying existing safety rules and by carrying out detailed risk analysis. This ensures a reduction in emissions but also an equivalent or superior level of safety versus traditional oil-based solutions.

In April, Lürssen announced that it had sold its first yacht with hydrogen fuel cells powered by methanol. In early February 2022, Sanlorenzo announced it was building a 50-meter hydrogen fuel cell-powered yacht in partnership with Siemens Energy. Sanlorenzo is increasing its focus on innovation with the support of numerous partners, including Volvo Penta, which will provide an innovative hybrid propulsion system combined with a hydrogen fuel cell that will be installed on board the Bgm 65hh (hydrogen-hybrid), a Bluegame multihull set to launch in 2025. Not to mention the Baglietto shipyard's currently ongoing BZERO project, which includes a solar-powered electroliser that generates H2. The H_2 is subsequently stored in hydride vessels connected with the fuel cell system. Indeed, the whole industry started an important innovative revolution along the path paved by the Paris Agreement and the more important COP 26. The Glasgow Climate Pact aims to turn the 2020s into a decade of climate-supportive strategies. The package of agreed decisions needs an unprecedent joint effort by key industries, including all the sectors of shipping and yachting. Since then, numerous advances have being made through completely new technology and new energy vectors.

Being the decarbonization a global target, it is required an extensive knowledge sharing among those hard-to-abate sectors (international transports, steel, cement, chemicals). The same is true for yachting: innovative engine technologies, electric power trains, fuel cells, and high-performance batteries. These are all opportunities of development that will benefit the whole mobility industry. Some of them still need to finalize their technology scale-up at a level of energy production, size and efficiency, to become a primary solution on board. It has to be mentioned that the yachting sector has always had a major constraint when it comes to new technologies application: the lack of volume to house this new equipment. It happened at the time of the selective catalytic reactor for the abatement of NOx and it will happen again with the alternative fuel systems.

The technology has to be mature enough to allow a scaling up of production, modularization and finally reduction of spaces dedicated to such systems. On the other hand, a well-distributed supply chain is required to drive further technological progress and price reduction, particularly at remote yet popular yachting marinas. New fuels need to be made available at a scale and price to become a viable option for the shipping industry and to promote a greener economy. Taking into account the building time for a yacht and the fact that this technology is not yet fully available, RINA issued a set of "fuel ready" notations based on a class approval that uses using design and construction assessments at different levels, following the timeline of the project and taking into account the readiness of the technology. RINA continues to support the yachting industry as verifier, but also as key advisor, especially if and when it is important to choose the solution to be applied.

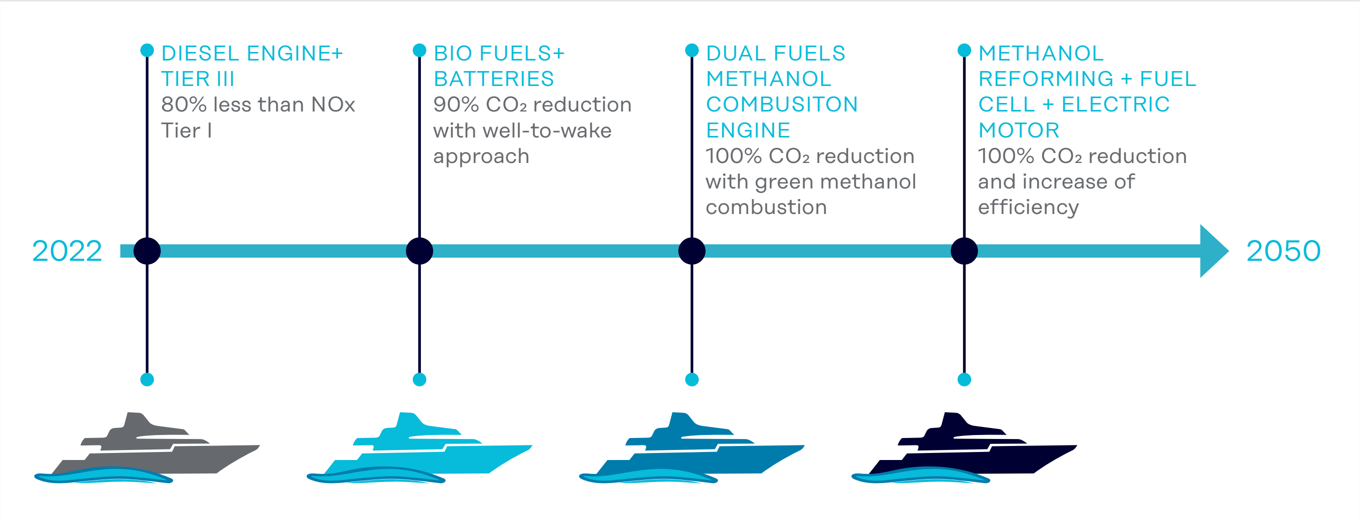

Figure 1 | Outlook of technology readiness in the yachting sector

The regulatory framework

The regulatory framework for alternative fuels is still partially under development, which is also related to the fact that there are increasing installations fueling the learning curves of all parties, mainly manufacturers and classification societies in particular.

The framework below is applicable as of the date this document is published, but regulations are changing at an unusual fast pace for the maritime sector.

The following rules generally apply for hydrogen-installations, however special projects could lead to additional rules to be observed:

- IGF Code MSC.391(95)
- IMO MSC.1-Circ./647 Interim guidelines for the safety of ships using fuel cell power installations
- IMO MSC.1-Circ.1212 and MSC.1-Circ.1455 for alternative design as required by flag
- RINA Rules Part C, Chapter 1, Appendix 14 (Hydrogen Fuelled Ships)
- RINA Rules Part F, Chapter 13, Section 38 (H_2 Fuelled Ready X1, X2, X3,.....)

For methanol the regulatory framework is still under development, however the following rules are in force:

- IGF Code MSC.391(95)
- IMO MSC 1.-Circ 1621 Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel
- RINA Rules Part C, Chapter 1, Appendix 15 (Methyl/Ethyl Alcohol Fuelled Ships)
- RINA Rules Part F, Chapter 13, Section 39 (Methyl/Ethyl Alcohol Fuelled Ready X1, X2, X3,.....)

Despite the lack of a comprehensive regulatory framework, Class has the ability to enable the implementation of new technology by using a different design approach based on risk assessment through the authorization of the Flag administration. This process, that is tailored on each specific case and merges regulatory aspects with experience and engineering considerations, has the aim to reach the same level of safety of conventional fuel oil system.

Biodiesel
Characteristics, production / bunkering, yacht design challenges

Characteristics

Biodiesel (FAME; Fatty Acid Methyl Ester) and renewable diesel (HVO; Hydrotreated Vegetable Oil) are renewable alternatives to fossil-derived diesel fuel. They are produced from an array of renewable feedstocks including rapeseed oil, used cooking oils (UCOs) and animal fats. Although often made from identical feedstocks, the processes used to make FAME and HVO are different, with distinct end uses. FAME is produced via biomass esterification, where fats are broken down and then reacted with methanol to produce a final product similar to fossil diesel, but with a higher oxygen content. Similarly to conventional diesel, biodiesel must comply with a CEN standard, EN14214.

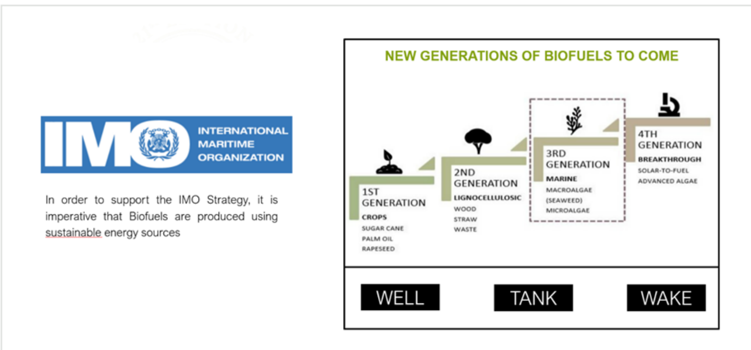

Figure 2 | New generation of biofuels to come

Production / Bunkering

Since 2006 biodiesel has been used as a drop-in fuel in the automotive industry in Europe. Article 3 of the Renewable Energy Directive sets out mandatory national overall targets and measures for the use of energy from renewable sources for all EU Member States. Each member state is responsible for making sure that by 2020, at least 10% of all modes of transportation in that member state will be fuelled by renewable energy. Biodiesel can be used 100% (B100) or in blends with diesel fuel. Blends are indicated by B##, which corresponds to the percentage of biodiesel in the blended fuel.

RINA MAXIMA

For example, a 20% blend of biodiesel with 80% diesel fuel is called B20. The EU is currently the world leader in producing and using biodiesel and renewable diesel in transport. Close to 200 plants are in operation across the EU, producing annually around 13 million tonnes of biodiesel. Most of this is consumed in France, Germany, Spain, Sweden, and Italy, which in 2018 cumulatively made up two-thirds of the EU biodiesel market. Other markets are smaller, but growing.

COMBUSTION ENGINE EMISSIONS (Tank-to-Wake) - DIESEL FUEL vs BIOFUEL

	100% Diesel fuel 0% Biofuel	75% Diesel fuel 25% Biofuel	50% Diesel fuel 50% Biofuel	25% Diesel fuel 75% Biofuel	10% Diesel fuel 90% Biofuel
CO2 [%]	basis	-6%	-6%	-6%	-10%
NOx [%]	basis	-11%	-15%	-21%	-21%
Exhaust Gas Temp.	basis	0%	-1%	2%	0%

- **Up to -90% CO_2 emissions (Well-To-Wake)**
- Renewable (non fossil fuels)
- Zero SOx emissions (no sulphur inside)
- Reduced particulate emissions
- Reduced engine wear

A simple step towards "net zero", indeed:
- Can be used in traditional combustion engines (100% hydrocarbon, like gasoline)
- Can be used pure or as a blend at different concentrations
- No CAPEX requirement

Figure 3 | Emission values belnding biofuels with DO

Yacht Design Challenges
The first time biodiesel is used on a yacht, it could release fuel tank deposits that might cause fuel filters to clog. After this initial period, a user can switch between biodiesel and petroleum diesel whenever needed or desired, without modification. However, the use of biodiesel in the maritime sector should always be checked and approved by the engine manufacturer. The other big challenge for biofuels is their availability. Actual production meets just a fraction of the market's expected demand. Moreover, the real sustainable biofuel should come from the 3rd and 4th generation source, that is algae farming (Fig.2), which is still far to being a viable option.

Methanol
Characteristics, production / bunkering, yacht design challenges

Characteristics
The handling of methanol is generally as easy as the handling of any other conventional liquid fuel (e.g. marine gas oil), with the exception that the low flash point related hazards needs to be addressed. It is easily detectable already in the range below 5 ppm. Methanol is an oxygen-rich fuel that combusts in an ICE (Internal Combustion Engine) emitting no sulphur oxides (SOx), a negligible amount of particulate matter (PM) and nitrogen oxides (NOx) and it CAN be used as hydrogen carrier (primary fuel) for the fuel cell technology. Additionally, methanol burns with a clear blue flame, that is smoke-free and difficult to see in daylight. It should be kept away from sources of ignition including heat, sparks, flames, and hot surfaces. The storage containers must be tightly closed when not in use and they should be located in well-ventilated and cool areas. Methanol can be toxic if swallowed, inhaled, or in contact with the skin, although skin absorption is a lower process than ingestion or inhalation. Breathing in mist or vapours should be avoided, and PPE should be used along with appropriate chemical-resistant gloves, whenever handling is necessary. Depending on the activity, respiratory protection may be required, and if it is swallowed, immediate medical attention is needed.

Production / Bunkering
Nowadays, methanol may be produced either from fossil fuels or biomass. Current methanol production from mega plants around the world is using fossil-based natural gas and coal as their feedstock. There are over 90 methanol plants worldwide, with a combined production capacity of around 110 million tonnes.

1. Methanol Institute, "The methanol industry." [Online]. Available: https://www.methanol.org/the-methanol-industry/. [Accessed: 04-Mar-2019].

Blue methanol, produced in combination with carbon capture and storage, offers a lower emissions profile. Production of green methanol, sourced from biomass or from captured CO_2 and renewable electricity sources and green hydrogen, is small but growing as producers recognize the demand signal being sent by the shipping industry. In fact, the aggregated installed capacity of blue and green methanol in the EU alone is projected to reach over 3 million tonnes per annum (mtpa) by 2023, which has increased from the just over 1 mtpa in 2020. More details on renewable methanol production facilities planning can be found at https://www.methanol.org/renewable/.

It is important to highlight that currently the bunkering of methanol is performed by truck. However, only minor modifications of existing bunkering infrastructure of yachts marina would be needed to allow also the supply of methanol to yachts. The FASTWATER (FAST Track to Clean and Carbon-Neutral WATERborne Transport through Gradual Introduction of Methanol Fuel) project, where RINA is involved as RO (Recognized Organization) of SMA (Swedish Maritime Administration), demonstrated that it is possible to bunker methanol from fueling station dedicated to the pilot boats, whose engines were upgraded to burn methanol (Figure 2). Moreover, an ISO standard for the specification of methanol as marine fuel is also under development (ISO/AWI 6583) by ISO Technical Committee ISO/TC 28/SC 4.

Figure 4 | Methanol (M97) refuelling facility at the Swedish Maritime Adminstration's Oxelösund pilot boat (Photo: J.Ellis) (https://www.fastwater.eu/images/fastwater/news/FASTWATER_D71.pdf)

Yacht Design Challenges
Methanol has an LHV (Lower Heating Value) of MJ/kg, which which is about half that of MGO (Marine Gas Oil). Thus, approximately twice as much fuel by weight shall be stored on board of a yacht, to obtain the same energy of a conventional fuel. Due to its density (796 kg/m3 at 15°C) being lower than MGO and water, an onboard fuel treatment system is not needed. However, its low viscosity requires design changes to the injection system of diesel engines to avoid poor combustion and poor lubricity in the cylinders. The flashpoint of methanol at 12°C is below the range of normal ambient conditions in a yacht, which is why safety protective measures must be taken to prevent exposure to air or ignition sources.

For methanol, due to the presence of protective cofferdams, additional space is normally required and storage tanks may be needed to be kept inerted. Methanol is a conductive polar solvent, so that galvanic and dissimilar metal corrosion in methanol service may be high if incompatible materials are placed in electrical contact with one another. Moreover, as methanol is a polar agent, it may be possible that some lubrication oils may not be fully miscible and, in this case, damages and leaks may occur if the lubrication oil is not selected accordingly to the engine maker´s instructions.

Finally, its explosive limits between 6% (lower) and 36% (upper) lead to the creation of hazardous zones, where only EX certified equipment may be fitted, the access is restricted and proper dedicated mechanical forced ventilation shall be granted.

The pilot and research projects like METHAPU, EffShip, SPIRETH, MethaShip, FASTWATER, LeanShips, proFlash, SUMMETH and Pa-X-ell2 demonstrated that methanol is a viable solution for yachts to be fitted with high speed engines (spark ignited), medium speed engines (dual fuel) and fuel cell power module. Existing engines may be retrofitted to burn methanol, new dual fuel engines, as well as fuel cells including methanol reforming unit, are available in the market (see Figure 5). The methanol reforming is a process requiring high temperatures that is difficult to keep stable and the long response time to transitional power demand should be compensated.

RINA is proud to be a front-runner on this methanol challenge.

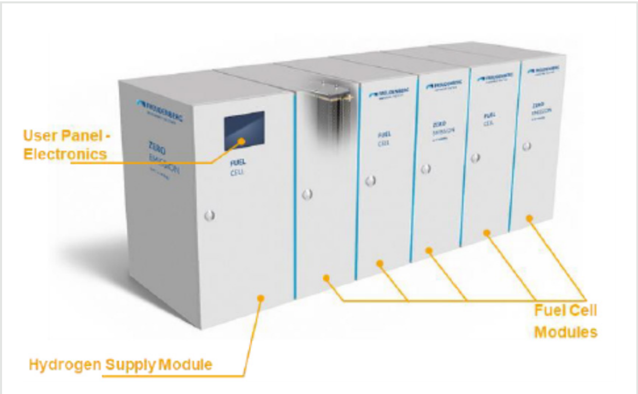

Figure 5 | Methanol fuel cell

Hydrogen
Characteristics, production / bunkering, yacht design challenges

Characteristics

The hydrogen gas is an equilibrium mixture of ortho-hydrogen and para-hydrogen and these molecules are chemically equivalent, with only very slightly difference in their physical properties. Under normal conditions, hydrogen atoms combine into molecular pairs because they are highly reactive. Hydrogen in pure form is an odorless, colorless, not toxic, whose streams are almost invisible in daylight. Among all fuels, hydrogen has the highest energy content at 120.2 MJ/kg and the energy per mass of hydrogen is about 2.8 times higher compared to MGO and even 5-6 times higher compared to methanol. Since the hydrogen fuel does not contain carbon or sulfur, combustion does not produce CO, CO2, sulfur oxides (SOx) or PM and when it is processed in a fuel cell, there is also no generation of nitrogen oxides (NOx). Compared to LNG, hydrogen has a 6-7 wider combustion range, 6-7 times higher maximum flame speed, and 15-20 smaller ignition energy, which leads to it being easier to ignite after a leakage in a closed space.

The low density of hydrogen also has an impact on its transport, where under standard conditions (1.013 bar and 0°C), hydrogen has a density of 0.0899 kg per cubic meter (m3), also called normal cubic meter (Nm3). If hydrogen is compressed to 200 bars, the density under standard conditions increases to 15.6 kg hydrogen per cubic meter, and at 500 bar it would reach 33 kg H_2 /m3.

Production / Bunkering

The hydrogen may be produced with several methods which are, as for methanol, identified by colors according to the industry process adopted and the type of energy source (Figure 6). Only 2% of the hydrogen produced globally is green hydrogen from electrolysis, meanwhile, 98% is grey or brown hydrogen from fossil fuels. The majority of hydrogen produced globally is connected to the ammonia production. The use of the current best processes for water electrolysis (PEM or alkaline electrolysis), which have an effective electrical efficiency of 70-82% producing 1 kg of hydrogen (which has a specific energy of 143 MJ/kg or about 40 kWh/kg), requires circa 50–55 kWh of electricity.

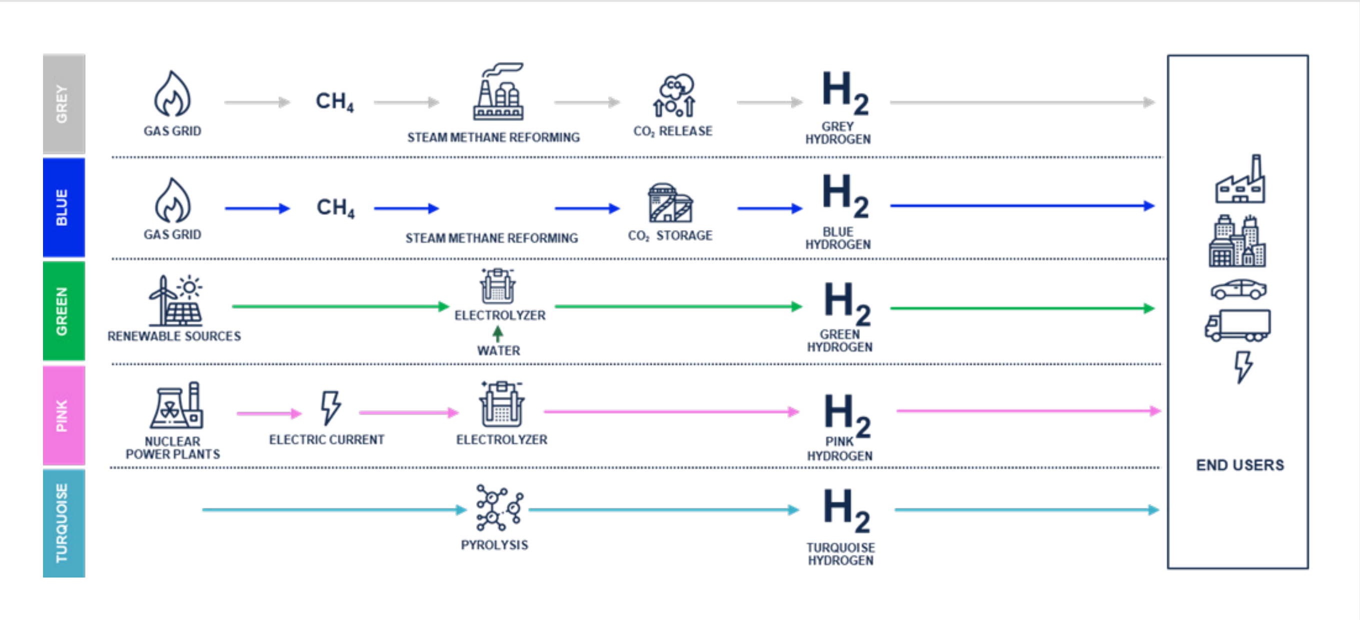

Figure 6 | Shades of H_2

It is important to highlight that currently the bunkering of hydrogen is performed only by truck. However, it is observed that in the automotive sector, some local compressed hydrogen facility with electrolyzers, compressors and high-pressure storage systems are built and many are in planning.

These facilities are normally designed according to internationally recognized standards such as ISO 19880-1 “Gaseous Hydrogen - Fuelling Station”, in order to supply compressed hydrogen to vehicles like cars, trucks and forklifts at 350 bar (H35) or at 700 bar (H70). The relevant technologies may be used for the development of similar bunkering system for yacht marina, as recently presented by companies Hynion As and Hyrex AS with their hydrogen floating fuelling station concept.

(https://www.hynion.com/news/hynion-and-hyrex-launches-floating-hydrogen-station-for-leisure-boats).

Yacht Design Challenges

Hydrogen has a mass-based energy density almost three times higher than that of liquid hydrocarbons such as MGO or LNG. However the volumetric energy density is comparatively low and, for storage purpose, its density has to be increased. There are several storage methods and they can be grouped into two categories:

- Physical-based systems like compressed gas, cold/cryo compressed and liquid hydrogen or
- Material-based like adsorbent, liquid organic, interstitial hydride, complex hydride, chemical hydrogen

From experience of recent hydrogen fuelled ship projects (ZEUS-Zero Emissions Ultimate Ship, B-Zero, Aurelia Car Carrier and others), where RINA is involved, mainly the high pressure (pressure range 350 bar - 700 bar, ambient temperature), metal hydride (pressure range 30 bar - 50 bar, ambient temperature) and liquefied containment systems (pressure range 5 - 15 bar, temperature -250 °C) are selected and, for the yachting sector, the first two seem more promising.

In general, for compressed hydrogen, the following hazards can be identified to be the most challenging in terms of installation: high pressure leading to higher probability for leakages, material embrittlement, wide range for the creation of explosive atmosphere (from 4% LEL up to 75% LEL in air), invisible flame and low ignition energy.

All the above mentioned hazards lead to the need to find on board of a yacht a dedicated space for the storage of hydrogen cylinders, provided with independent ventilation system of big size to allow possible hydrogen leakages to be diluted and vented safely to the open atmosphere.

Of course hazardous zones categorization and restricted access are even more strict that in the case of methanol, limiting further the possibility for the arrangement of other spaces.

Having pure hydrogen on board will allow the use of fuel cell power modules in an easier way, due to the fact that reforming unit is not required and big benefits on the response time to load steps are noticed. Furthermore, hybrid configuration with spark-ignited hydrogen engines would be possible with some interesting advantages that could facilitate the transition to the use of H2 on board, for example increasing the reliability of the whole propulsion system (see Figure 8).

Figure 7 | Internal Combustion Engine running on 100% H2

HYDROGEN ENGINES AND FUEL CELLS ARE BOTH
PROMISING ZERO CARBON SOLUTIONS FOR MARINE APPLICATIONS

INTERNAL COMBUSTION ENGINE	ADVANTAGE TO	FUEL CELLS
-44% + expectation for DI H_2 fuelled ICE	→	60%+ electrical efficiency (peak at 25% load)
Low engine-out NOx enabled by lean low-temperature combustion. Trace oil derived emissions	→	No emissions
Substantial NVH effort	→	Quiet
Lower costs, reliability and well understood	←	Forecasted to be competitive by 2030
Tolerant to fuel contaminants	←	Fuel purity required
Diesel ICEs durable for > 10,000 hours H_2 ICEs expected to be similar	←	Target > 10,000 hours

Figure 8 | ICE fulled by H2 and Fuel Cell comparison

Conclusions

Superyachts, by the nature of their service, have a unique set of requirements and operating parameters. The way in which superyachts are operated and used creates some unavoidable differences from the commercial shipping fleet. This leads to unique challenges that only a united superyacht community can face and tackle. There are currently several projects featuring both hydrogen and methanol as a fuel source, even if they are all integrating a hybrid propulsion system with an internal combustion engine. The best option at the present is the combination of solutions.

Taking into consideration the current conventional propulsion arrangement of superyachts (Figure 9).

The use of methanol and hydrogen, fuel cell and engines may lead to the following hybrid propulsion concept scenarios:

Short Term (5 years)
- Propulsion Diesel Engines
- Fuel Cell System (Hotel Load)
- Battery Pack
- Shore Power Connection
- DC Power Distribution
- Fuel: Hydrogen / Methanol

Long Term (10 years)
- Full Electric (E-Motors)
- Redundant Fuel Cell System
- Redundant Battery Pack
- Shore Power Connection
- DC Power Distribution
- Fuel: Hydrogen / Methanol

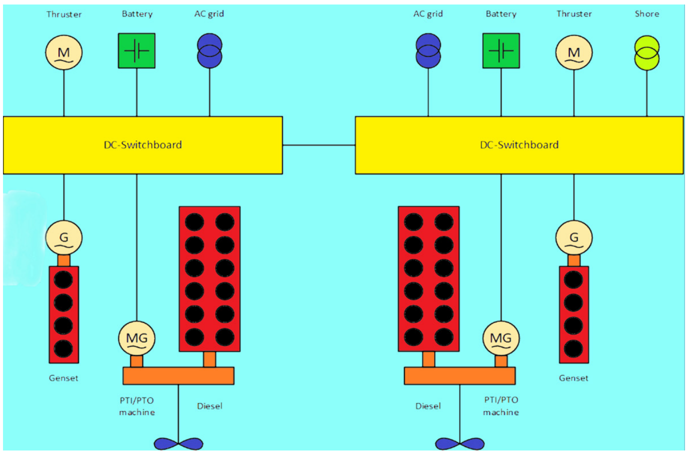

Figure 9 | Typical power configurations on yachts

In the first scenario, the dual fuel engines (e.g. Methanol/MGO or Hydrogen/MGO), used for propulsion, and the fuel cell, for the hotel load, will allow the yacht to be zero emissions in port and lowered emissions during navigation. In the second scenario, the engines will be replaced by E-motors and the fuel cell combined with the battery with a higher capacity will give the needed power for propulsion and hotel load, allowing a full zero emissions concept.