SWOTing

The Potential of Low and Zero Emission Fuels to the Maritime Sector

VENUE:
Experience Center of PwC Cyprus

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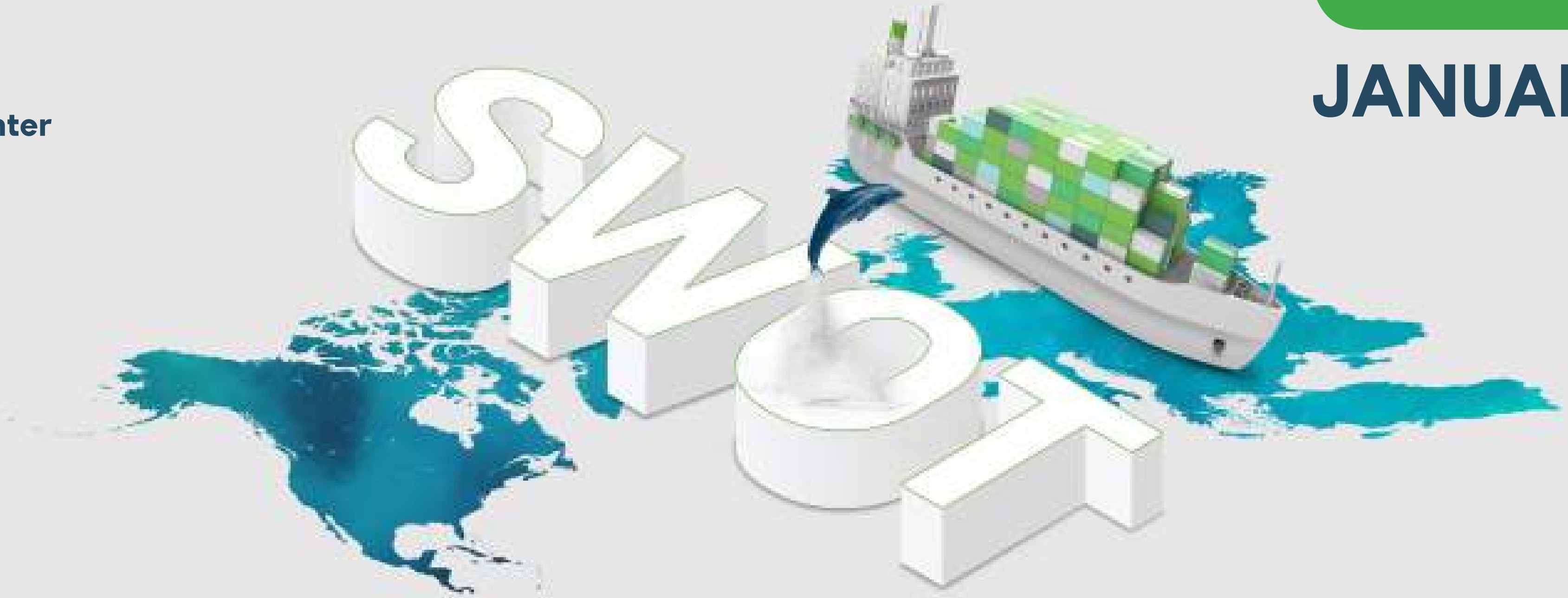
CONCLUSIONS

FROM SWOT ANALYSIS

JANUARY 19th, 2023



Building Together a Greener Future for Shipping

Organised by:

Shipping Deputy Ministry
Republic of Cyprus

In association with:

Division of Energy and Innovation
UNIVERSITY OF HOUSTON

COMPARING FOUR ALTERNATIVE MARINE FUELS

HYDROGEN – AMMONIA – BIOFUEL – METHANOL

The Shipping Deputy Ministry (SDM) of Cyprus in association with the University of Houston organized the interactive hybrid event; "*SWOT-ing the potential of low- and zero- emission fuels in the maritime sector*". Held on 19th January 2023, the event was hosted by PwC's Experience Centre in Nicosia, Cyprus, a cutting-edge facility for modern and innovative solutions and experiences. The three-hour event brought together more than 400 participants from around the world, in an interactive and participatory way for a live hybrid SWOT analysis for four alternative fuels; hydrogen, ammonia, biofuel and methanol.

Panelists from the industry and academia[1], moderated by the Shipping Deputy Minister Mr. Vassilios Demetriades, examined the safety, costs, maturity, and availability of new bunker fuels, drawing conclusions that provide a useful summary of the current alternative fuel landscape.

The above team of experts formulated the SWOT analysis matrix hologrammatically in real time with live support from the audience.

The conclusions in this report summarise the outcomes of further evaluation of the SWOT Analysis, comparing hydrogen, ammonia, biofuel and methanol in relation to seven key parameters;

The SWOT Analysis matrix for each one of the fuel technologies under examination is presented at the end of this report and the entire event is recorded and available on YouTube [link].

[1] Dr Joe Powell – University of Houston Energy Transition Institute, Dr. John Kokarakis - Technical Director SEEBA Zone Bureau Veritas, Dr. Mike Harold - University of Houston Chemical and Bimolecular Engineering Department, Dimitrios V. Lyridis - Associate Professor, National Technical University of Athens, School of Naval Architecture & Marine Engineering, Dr. Lakis Mountziaris - University of Houston Chemical and Bimolecular Engineering Department, Dr. Leonidas Ntziachristos - Professor, Mechanical Engineering Department, Aristotle University, Thessaloniki, Chris Angelides - ESG, Energy Transition and Sustainability Expert.

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Safety and compatibility risks associated with the use of low and/or zero emissions fuels with existing vessel main engines

One of the main strengths of biofuels is the compatibility with the existing main engines, as well as the existing bunkering infrastructure in the port facilities. There are no additional safety risks in comparison with traditional marine fuels and as the technical characteristics are similar to traditional fossil fuels, the existing main engine does not require major modification for use. In addition, biofuel alone can be consumed onboard, or it can be dropped in and blended with conventional marine fuel oil (provisions by the ISO 8217 marine fuel standard should be considered).

Methanol is also compatible with dual fuel main engines (with little impact on new building cost) and existing bunkering infrastructure with relatively low safety risks. In fact, bunkering infrastructure for methanol is cheaper than the one for LNG. Ammonia on the other hand is very toxic. Internal combustion engines (ICE) compatible with ammonia, are still under development, and require the use of a pilot fuel (even up to 30%). For the time being ammonia can be burnt in fuel cells and has a higher volumetric energy density (+50%) than hydrogen. When it comes to storage, ammonia is considered easier compared to hydrogen as it can be liquefied at room temperature and stored in LPG tanks.

Hydrogen has been used in ICE's but mainly as a supplementary/mixed fuel blended with conventional gas in dual fuel (DF) engines. In DF ICE's, emissions can be reduced according to the percentage of hydrogen fuel consumed. Currently, as with the case of ammonia, hydrogen (with high purity) can, and is, used in fuel cells. Although not toxic, hydrogen is explosive and has very high safety risks . Bunkering infrastructure is virtually non-existent due to safety concerns and very high associated costs.

In addition to the above comments, crew safety onboard is considered of paramount importance. All parties involved should focus on this aspect and should work towards developing training modules and materials in order to ensure the highest level of safety for the crew.

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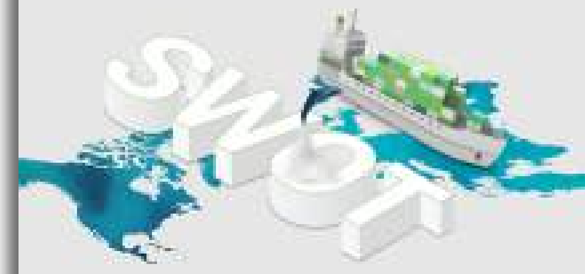

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Low / Zero and carbon neutral fuels

Biofuel and methanol are carbon-based fuels. Most of methanol is currently produced from natural gas or coal. Sustainable "green" production from biomass, or reaction of captured CO_2 with H_2 is also possible at higher cost. Meanwhile hydrogen has the potential to be a zero-carbon marine fuel when it is consumed in a fuel cell or into mono-fuel internal combustion engines. Consumption of hydrogen as a mixed fuel in DF ICE's can significantly reduce carbon emissions. Ammonia is a carbon free fuel producing no CO_2 or SO_x emissions on its own merit, but in use in ICE's overall emissions depend on the type of pilot fuel selected (that may be carbon based).

Storage capacity onboard

Technological advances are needed for hydrogen to be considered as a viable, large-scale, commercial fuel option, particularly for applications with large quantities that may require increased space on board. For long routes and deep-sea voyages, storage may need to be in liquid state (-252°C). Hydrogen-fueled vessels trading close to bunkering stations with the possibility of frequent bunkering, may eliminate the problems of limited fuel energy content on board or cargo space loss. For liquefied hydrogen at low pressures, the energy loss during storage and boil-off gas generation may be a challenge for long-term storage applications.

Due to low energy content, ammonia (although higher than hydrogen) requires bigger storage tanks (2 to 3 times more than conventional fuels) and its location is one of the most critical design factors. Cargo capacity of the vessel is expected to decrease based on the use of an ammonia ICE or ammonia fuel cell arrangement. The additional space for the fuel, due to lower energy density, may in theory require larger vessel sizes, but in practice it decreases cargo space or more frequent bunkering is required.

Methanol requires high storage volume and load requirements. Methanol is a colorless liquid at ambient temperature and pressure. It is easier to store and handle than ammonia and hydrogen fuels.

Thus, storage capacity and requirements of the above alternative fuels can be considered as a weakness in comparison to biofuels, which do not require more space than conventional fossil fuel oil onboard (although oxidative deterioration prevents storage for very long period of time).

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Global availability and supply / bunkering challenges (short – medium – long term)

Bunkering and distribution, and more specifically the availability of port infrastructure, does not exist or is insufficient to accommodate the recommended quantities of the alternative fuels for the fleet (especially hydrogen). Methanol and ammonia are available at approximately 100 ports across the globe. On the other hand, although for biofuels the necessary bunkering infrastructure is compatible with the current one for fossil oil, fuel availability is limited to central Europe and few other non-European ports.

Environmental footprint (on well-to-wake basis)

Ammonia production process well-to-tank (WTT) could produce emissions in case non-renewable feedstock is used as its production is very energy intensive. Alternatively, it can be produced by electrolysis of water with renewable energy to eliminate the emissions from feedstock and the production process.

Hydrogen is characterized by having a very low tank-to-wake (TTW) emissions impact, which does not consider the energy source during the production process. However, the life cycle of hydrogen production must be considered to evaluate the overall emissions of greenhouse gas (GHG) from hydrogen. Currently, hydrogen production (grey or even blue hydrogen, when carbon capture is applied) uses a lot of energy and produces a lot of CO_2. However, the use of renewable energy sources may eventually eliminate this issue (green hydrogen.)

Methanol can be characterized as a transitional fuel due to GHG emissions on a well-to-wake (WTW) basis. On the other hand, although biofuels and synthetic methanol made from bio-genic sources or synthetically from direct air capture of CO2 are carbon based and emit similar amounts of GHG to conventional fuels on a TTW basis, on a WTW basis, they can be considered carbon-neutral.

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Fuel cycle costs / market conditions

The cost of producing green hydrogen is high, especially at small scale and the production scale is relatively low when compared to the needs of the maritime industry. In addition, cost of hydrogen fuel cells is currently approximately 165$/KW (figures are rapidly changing).

However, although biofuels can be used with minimal retrofit cost on vessels, actual cost of fuel may be higher as feedstock may represent as much as 75% of the production cost. Ammonia is produced in very high quantities worldwide (as it is used in the agricultural industry among other sectors), but as a fuel its price is relatively high.

Fuel characteristics, condition of carriage

Ammonia (to a higher extent) and methanol are characterized by high toxicity, which can be considered as one of the most important weaknesses with regards to storage and handling.

Methanol is also flammable with a flash point below 60°C. MSC Circ. 1621 and class rules mandate that a cofferdam of minimum width of 600 mm must be constructed around the storage tank. In addition, inert gas must be on the vapor space of the methanol tank. The cofferdam, which must have methanol detectors, occupies a lot of space.

Hydrogen is colourless, odourless and burns invisibly. There remains a need to formulate a regulatory framework for hydrogen.

Ammonia and hydrogen in ICE's require a pilot fuel due to high auto-ignition temperature. Nevertheless, methanol engines with a relatively lower auto-ignition temperature of around 400°C, also require a pilot fuel.

Ammonia produces no CO_2 or SO_X emission but it does emit NO_X which must be abated; selective catalytic reaction (SCR) is required. Biofuels present no significant additional problems or risks in this area than conventional fossil fuel oil.

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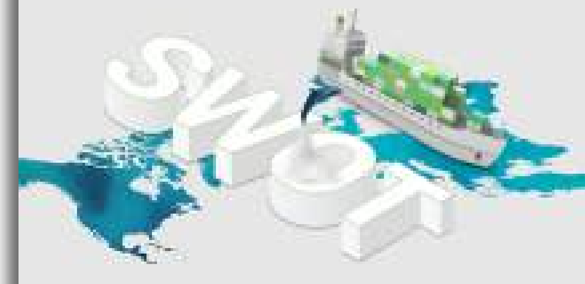

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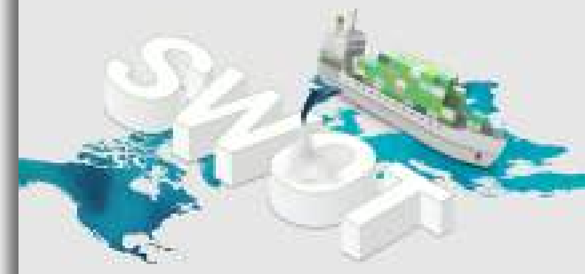
Timeline of maturity and uptake of each fuel

The most technologically mature fuels are 2nd generation biofuels (the preferable 3rd generation biofuels are still not technologically mature) and fossil-derived methanol. Given that there is competition with other sectors (especially aviation) and limited availability, it does not appear that biofuels will be dominating the fuel options of the future in shipping. However, they can be blended with other fuels or act as pilot fuels in the combustion of cleaner renewable fuels such as green ammonia.

Methanol has high technological maturity, but improvement is needed along with upscaling in the production of green methanol which today is 0.2% of the total.

Hydrogen and ammonia are currently large volume chemicals, but sustainable green or blue (from natural gas) pathways are expensive. Upscaling of clean or sustainable production routes for both, storage for hydrogen and safety issues for ammonia must be overcome. It is expected that ammonia and hydrogen take more than a decade to emerge as viable options.

Methanol and biofuels are expected to proliferate more within the next five years.



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Hydrogen

S (Strengths)

- Clean fuel
- Zero emission (fuel cell)
- Energy density
- Unlimited availability in water
- Non-toxic
- Flexibility of utilization (ICE & fuel cell)

W (Weaknesses)

- Cost of infrastructure for storage / distr.
- Burns invisibly
- High auto-ignition temp.
- Pilot fuel needed
- Lack of infrastructure
- Flammable, colorless, odorless, non-visible flame

O (Opportunities)

- Integrate among many industry uses
- Advancements in fuel cell technology
- Green hydrogen in countries with high sunshine / wind
- Floating platform via electrolysis
- New storage modes

T (Threats)

- Leakage challenges – Global warming from hydrogen is 10 times higher than CO_2
- Difficult and costly to compress
- Community acceptance concerns
- Production cost remains high
- Water scarcity issues – High quantity of water for electrolysis ($9t\text{-}H_2O/1t\text{-}H_2$)

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Methanol

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Ammonia

S
- Experience in handling
- Well established transport / storage infrastructure
- Mature production methodology
- Low flammability
- Flexibility of utilization

W
- Causes stress corrosion cracking
- Selective Catalytic Reaction (SCR) requirements
- High auto-ignition temp. mandates pilot fuel
- NO_x formation
- Low energy density (1:3 to heavy oil density)

O
- Floating platform for ammonia production
- Green NH_3 from renewable energy
- Available in many ports around the world
- Utilization of experience gained from LPG carriers

T
- Ammonia discharge to sea
- Public acceptance needed
- Toxicity
- High cost gap between green & grey ammonia

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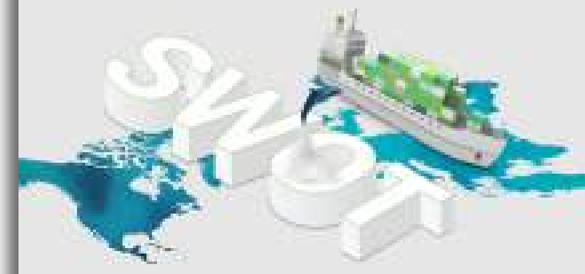

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Biofuels

S (Strengths)

- Ambient temp. / pressure storage
- Compatible with existing ME & bunkering infrastructure
- Blended with conventional marine fuels
- Biodiesel & HVO as a drop in fuel
- High energy density / heating value equal to MFO

W (Weaknesses)

- Land use constraints
- Emissions depend on supply chain
- Regulatory challenges
- Limited availability of feedstock relative to total global energy needs
- Not zero emission
- Biofuels (biodiesel, SVO) corrosive to fuel systems

O (Opportunities)

- Waste to energy
- Carbon capture resulting in negative emissions
- Promoting circular economy
- R&D to develop lower cost 3rd & 4th generation biofuels
- Funding opportunities for research on biofuels
- Successful trials on ocean-going vessels (use of biofuels)

T (Threats)

- Public backlash against land use
- OEM warranty issues
- Competing with food supply (ethical issues)
- CO_2 emissions from poor land use
- Insufficient supply

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Methanol

S | W
O | T

Strengths

- Security of supply
- Chemically stable, liquid fuel in ambient conditions
- Potential for duel fuel engines / early deployment for new vessel design
- Shipping regulations in place
- Biodegradable

Weaknesses

- Low viscosity
- Energy intensive
- Limited availability of bio-feedstocks, wastes or renewable natural gas
- Toxicity
- Not zero emissions

Opportunities

- Competitive price
- Engine availability
- R&D for integrated CO_2 capture
- Multiple pathways to production

Threats

- Corrosive behavior
- Public concerns
- Other industries might tap into this

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