Solutions for shipping to meet IMO 2050

Giosuè Vezzuto
Executive Vice President, Marine

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The revised strategy increases the level of ambition. The new target is a net zero emission state, close to 2050 (which cannot be interpreted in a single manner, although it is subject to revision in 2028).

The reduction of carbon intensity by 40% in 2030, remains as before.

In order to verify the progress of reduction, two checkpoints have been introduced, in 2030 and 2040. These checkpoints do not address carbon intensity, but total emissions. The target is that, compared to 2008, in 2030 to have a reduction of GHG emissions by 20% and in 2040 by 70%, although striving for 30% and 80% respectively.

As already known, the CII is subject for review in 2026, and there is no doubt that the reduction factor Z will decrease more sharply in order to arrive us at net zero close to 2050.
Meeting the IMO target for GHG reduction

Alternative Fuels

(i) Availability
(ii) Cost are key concerns

Fossil Fuel & Carbon Capture

Post combustion

Pre combustion

H2 on board
Outcome of MEPC80: the view on fuels

- Guidelines for the Life Cycle Assessment (LCA) of a fuel were adopted.

  This is very important in regards ammonia and methanol. Very rightly IMO wishes that the decarbonization of shipping does not shift emissions to other sectors. Seen under the light of LCA, the grey ammonia and methanol will increase sharply the GHG emissions of a ship, because their production is linked with huge emissions of GHG. Only blue and green ammonia and methanol can be considered for use, which makes their availability and cost much more challenging for shipping.

- The use of biofuels will fall under critical observation

  Only fuels, certified by international bodies, which succeed a well-to-wake reduction of GHG of 65% compared to Marine Gas Oil, can be considered as biofuels, and be assigned a reduced carbon emission factor. In all other cases, they will have the emission factor of the corresponding fossil fuel. In this regard, the list of possible biofuels that can be used becomes short, with limited availability and very expensive. Also bio-gas cannot be considered as carbon negative.
The case of Bio-fuels

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetable Oils found in food crops</td>
<td>Agricultural Non-food crop feedstocks, and forest residues</td>
<td>Specially energy source such as algae</td>
<td>Genetically modified (GM) algae to enhance biofuel production</td>
<td></td>
</tr>
<tr>
<td>Production Method</td>
<td>Fermentation, Transesterification (FAME), Hydrotreating (HVO)</td>
<td>Fischer Tropsch</td>
<td>Fischer Tropsch</td>
<td></td>
</tr>
<tr>
<td>Common Types</td>
<td>FAME, HVO</td>
<td>FT Diesel</td>
<td></td>
<td></td>
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</tbody>
</table>

Emissions reduction potential depends on feedstock, production method and supply chain. Biofuel must be accompanied with certification issued by ISCC or a similarly approved auditing body (RSB).

- Bio fuels have short “shelf-life” due to very low oxidation stability

The effect of Bio-fuels in combustion & emissions:

- Advance of injection timing
- Modification of ignition timing due to lower LCV
- Shorter Ignition delay due to higher CN
- Effect (+ / -) on NOx emissions: this varies, less NOx usually come at cost for SFOC
- Reduce visible smoke & PM
- Reduced CO and HC emissions
Not enough green energy for green fuels

Annual production of Green energy  8,300 TWh \(^{(1)}\)

Energy for production of green ammonia
Green Ammonia for shipping  38.2 GJ/MT NH3 \(^{(2)}\)
Green Energy for ammonia for shipping  661 Million MT

Power-to-methanol conversion efficiency
48.2% \(^{(3)}\)

Energy content of Methanol
23.0 GJ/MT
Green Methanol for shipping  618 Million MT
Green Energy for methanol for shipping  8,191 TWh

Sources:
2. https://pubs.rsc.org/en/content/articlelanding/2020/ee/c9ee02873k
## Fuel management on board

<table>
<thead>
<tr>
<th></th>
<th>Fuel Oil</th>
<th>LNG</th>
<th>Methanol</th>
<th>Ammonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy content (MJ/kg)</td>
<td>41</td>
<td>50</td>
<td>19.9</td>
<td>18.6</td>
</tr>
<tr>
<td>Density (MT/m$^3$)</td>
<td>0.96</td>
<td>0.45</td>
<td>0.792</td>
<td>0.73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Ref</th>
<th>-19%</th>
<th>+206%</th>
<th>+220%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>Ref</td>
<td>+73%</td>
<td>+250%</td>
<td>+290%</td>
</tr>
<tr>
<td>Volume</td>
<td>Ref</td>
<td>-25%</td>
<td>-9%</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*With CH4 slip*  

- Extra mass will have impact on DWT  
- Standard arrangement of fuel Tks needs to change
Fuel Price vs. Fuel Availability

Reduced fuel availability yields skyrocketing prices

Fuel cost is > 60% of total ship operating costs
Hydrogen is dream fuel

We cannot realistically anticipate that we can solve the problems around production, transportation, delivery and storage of hydrogen.

<table>
<thead>
<tr>
<th>BENEFITS</th>
<th>CHALLENGES</th>
</tr>
</thead>
</table>
| No SOx, PM, CO2 emissions | • Very small production globally  
• No distribution & bunker infrastructure  
• Very low energy density (1/2.5 of LNG), very big tank  
• Great energy loss for liquefaction  
• Liquid phase temperature interval is only 13oC; Insulation of LH2 tanks is critical  
• Material challenges, at very low cryogenic temperatures  
• Little storage time, not very suitable for long voyages |
Steam Methane Reforming

Steam Methane Reforming (SMR) is a process that converts natural gas (methane) into hydrogen and carbon dioxide. The process can be represented by the following chemical reactions:

Fuel Reforming:
\[ CH_4 + 2H_2O \rightarrow CO + 3H_2 \]

Water Gas Shift:
\[ CO + H_2O \rightarrow CO_2 + H_2 \]

The process involves the following steps:

1. **Steam Reforming:** Natural gas (LNG) is mixed with steam and heated to high temperatures, resulting in the production of hydrogen and carbon monoxide. The reaction is represented as:
   \[ CH_4 + 2H_2O \rightarrow CO + 3H_2 \]

2. **Water Gas Shift:** The carbon monoxide produced in the first step is reacted with steam to convert it into carbon dioxide and additional hydrogen. The reaction is represented as:
   \[ CO + H_2O \rightarrow CO_2 + H_2 \]

3. **Heat Exchange:** The heat generated during the reforming process is used to preheat the feedstock, optimizing the efficiency of the process.

4. **Internal Combustion Engine:** The produced hydrogen can be used as fuel for internal combustion engines, providing a clean and efficient source of power.

5. **Conversion to Hydrogen:** The final step involves the conversion of the gases produced into pure hydrogen, ready for use in various applications.
The selection of fuel towards 2050

The fuel is produced on board

Using available and mature technology

- Novel application instead of novel technology
- No need for storage & supply of H2

Relying on abundantly available fossil fuel (LNG) which will always be much less expensive than any other alternative fuel

CO2 is captured before the combustion of fuel, and is liquefied by means of cryogenic temperature of LNG

- Less space, cost, and energy consumption
- CCUS is a global solution

Disconnected from the need to produce and supply/distribute a new fuel
Fuel Cells

- Mature Technology
- Very high power density
- Only water vapor as emission
- Rapid response to load changes
The benefits of Hydrogen + methane

Without Tuning

With Tuning

Source: Wärtsilä
Onboard Hydrogen Generators
## Hydrogen as fuel

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Safe fuel/less hazard, when parameter is:</th>
<th>Gasoline</th>
<th>Methane</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>Low</td>
<td>4.4</td>
<td>0.65</td>
<td>0.084</td>
</tr>
<tr>
<td>Diffusion coefficient in air</td>
<td>cm²/sec</td>
<td>High</td>
<td>0.05</td>
<td>0.16</td>
<td>0.61</td>
</tr>
<tr>
<td>Specific heat at const. P</td>
<td>J/gK</td>
<td>High</td>
<td>1.2</td>
<td>2.22</td>
<td>14.89</td>
</tr>
<tr>
<td>Ignition limits in air</td>
<td>vol %</td>
<td>Narrow range</td>
<td>1.0-7.0</td>
<td>5.0-17.0</td>
<td>4.0-75.0</td>
</tr>
<tr>
<td>Ignition energy in air</td>
<td>mJ</td>
<td>High</td>
<td>0.24</td>
<td>0.29</td>
<td>0.02</td>
</tr>
<tr>
<td>Ignition temperature</td>
<td>deg.C</td>
<td>High</td>
<td>228-471</td>
<td>540</td>
<td>585</td>
</tr>
<tr>
<td>Flame temperature in air</td>
<td>deg.C</td>
<td>Low</td>
<td>2,197</td>
<td>1,875</td>
<td>2,045</td>
</tr>
<tr>
<td>Explosion energy</td>
<td>gTNT/kJ</td>
<td>Low</td>
<td>0.25</td>
<td>0.19</td>
<td>0.17</td>
</tr>
<tr>
<td>Flame emissivity</td>
<td>%</td>
<td>Low</td>
<td>34-43</td>
<td>25-33</td>
<td>17-25</td>
</tr>
</tbody>
</table>

- The risk of hydrogen explosion is minimal
- Although hydrogen can burn in low concentrations, an explosion of hydrogen is very difficult to occur
- It blazes with little heat radiation, therefore only things immediately next to the flame would burn
COP27 : Solutions for carbon intensive industries

Cement, iron and steel, and chemicals / petrochemicals industries are the most significant industrial CO2 emitters, accounting for about 25% of total CO2 emissions globally and 66% of the industrial sector.

Their decarbonization of these industries is a top priority

The solutions presented fall into two categories:

- **Technology-based solutions**: carbon capture utilization and storage (CCUS); hydrogen; industrial energy efficiency; nuclear power and heat; electrification coupled with increased renewables
- **Concept-based solutions**: Circular Carbon Economy (CCE) and Industrial Clusters approach

It is reasonable that shipping shares solution with other industries (CCUS)
The removal of CO2 from reformed gases is a physical process and does not involve or require the use of chemicals.

Due to its very complex nature (heat & mass transfer process sensitive to hydromechanic and thermodynamic factors), the post combustion is very sensitive to vibrations and it is highly unlikely that it will perform on board a ship.

The post combustion is very sensitive to impurities (NOx, SOx, PM): their presence will rapidly degrade the chemical solvent, while their removal needs higher standards that catalysts and scrubbers.
Validation of concept from Cambridge

Advantages:
- H&S: Higher CO2 concentrations than Post-combustion CCS makes PSA possible; no amine issues.
- H&S: No on-board H2 storage; physical H2 path from production to consumption very short.
- Financial: On-board SMR+PSA Pre-combustion CCS probably less bulky than Post-combustion Amine CCS; no large LH2 boil-off; likely to have smaller cargo loss compared to LH2 option.
- Gradual decarbonization: if engine can use variable LNG+H2 mixtures, IMO trajectory can be met progressively; easier for shipowners to invest (less risk).
- Methane slip: likely to be improved (even small amounts of H2 can have drastic effect on CH4 slip)

On-board partial LNG reforming: overall efficiency vs CO2 removal

CO2 capture from reformate only
Reformer & CCS energy penalty @ 100% LNG conversion, using WHR
Needed to capture heater CO2
Full capture of CO2 (from reformate & from SMR heater)
For comparison: full capture of CO2 from the engine with Post-engine Amine CCS

Better overall efficiency than post-engine CO2 capture.
The case of Suezmax tanker

New Partner: [Company Logos]

41% reduction of EEDI
IMO2030 compliant!
The development of CII

Depending on: operating speed & accepted rate of CII
different options are available to Owner for compliance
The cost for CO2 reduction

- Standard DF ship
- 4 S on LNG
- 4 S on LNG + 10% H2
- 4 S on LNG + 30% H2
- 4 S on LNG + 60% H2
Proposal accepted by major Greek Owner

Angelicoussis Group advances first bulk carrier design to exceed IMO 2050

Dual-fuel, LNG/hydrogen, newcastlemax is being developed in conjunction with Rina and Shanghai Design & Research Institute

18 Nov 2022 | NEWS

Angelicoussis Group developing bulker that produces hydrogen on board

Greek owner's Maran Dry Management teaming with Rina and SDARI for innovative dual-fuel newcastlemax
European Regulations

- **Fit for 55** * (All ships > 5,000 GT) 
  Pay the cost for:
  100% of the GHG emissions within EU ports and from voyages between EU ports
  50% of the GHG emissions from voyages to or from EU ports

  Emissions to be considered:
  CO$_2$ from 1 January 2024
  Methane (CH$_4$) and nitrous oxide (N$_2$O) from 1 January 2026

  Phase-in:
  40% of the verified aggregated emissions reported for 2024;
  70% of the verified aggregated emissions reported for 2025;
  100% of verified aggregated emissions reported for 2026 and each year thereafter

- **Fuel EU** * (All ships > 5,000 GT) 
  The yearly average GHG intensity of the energy used on-board by a ship shall not exceed the reference value, which is reduced by an increasing % from 2% in 2025 up to 80% in 2050
## Implications by EU regulations

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<th>ANNUAL</th>
<th>EMISSIONS COVERED BY ETS</th>
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<td>100 EUR/MT</td>
<td>Consumption</td>
<td>CO2 emissions</td>
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Aside from cost benefit of ETS, and regardless who will pay this (Owner or Charterer), As pr FuelEU, the need to reduce the carbon intensity of energy consumed on board, **REMAINS**
Thank you for your attention

Giosuè Vezzuto
Executive Vice President, Marine