# Road to 2050

## *The Carbon Capture Technical Journal*

*Unveiling the decarbonization solutions for the shipping industry to approach the challenges of 2030 and 2050.*

Issue 01 / 2022

ECOSPRAY
technologies for the planet

# Road to 2050



## The 2050 horizon

Decarbonization is undoubtedly the most imperative priority in the maritime industry and, at the same time, it represents a crucial opportunity. The latest technologies, environmental awareness, sustainability and regulations are the key drivers towards carbon neutrality.
Ecospray has mapped out its path towards decarbonization with remarkable technologies and innovative approaches to achieving the 2050 zero emissions target. Discover all the details in the following pages and follow the progress of our projects.

## Preparing for the future

Ecospray is developing a range of different customized technologies to help shipowners find the right solution for decarbonization. One of these, which we have been working on for more than two years in collaboration with universities and research centers, includes $CO_2$ capture and fuel cell technology.
This unique solution, based on Molten Carbonate Fuel Cells (MCFC) reduces costs and environmental impact, coupling carbon capture with energy production simultaneously. At the same time, other solutions for carbon capture through chemical adsorption (for example, carbon capture with amines or lime milk) are under development, with the goal of providing different applications based on shipowners'needs.

## Carbon capture and storage (CCS) drivers for the marine industry

It is well known that without carbon dioxide capture and storage it will be impossible to keep the global temperature rise below 2C°. However, there are further reasons for the marine industry to start thinking about implementing CCS solutions.
Aside from ensuring compliance with the IMO targets for 2030 and 2050, carbon taxes are likely to appear and CCS is the best way to avoid a rise in costs.
Not only that, but large-scale investments and subsidization are ongoing (EU and US) to support climate mitigation measures, and CCS is the cheapest method, compared to the switch to renewable fuels that are still very expensive for marine applications.

## Challenges for shipowners and shipbuilders

**1.** Time
Short-term measures that must be complied with starting from 2023.

**2.** Lack of Clarity
Limits, reduction rates and calculation guidelines are still a work in progress.

**3.** Complexity
A wide and constantly changing landscape of new fuels and technologies.

### A clear vision for the future

*"We have made a choice for our future. We truly believe that all our technologies for the planet actively support decarbonization and the creation of green power."*

Maurizio Archetti

## Dealing with an uncertain scenario

**IMO set challenging targets for Greenhouse Gas (GHG) emissions from the marine industry, with two major milestones in 2030 and 2050. In terms of applicability, the regulatory framework still requires clarity.**

DISCOVER THE IMO TIMELINE

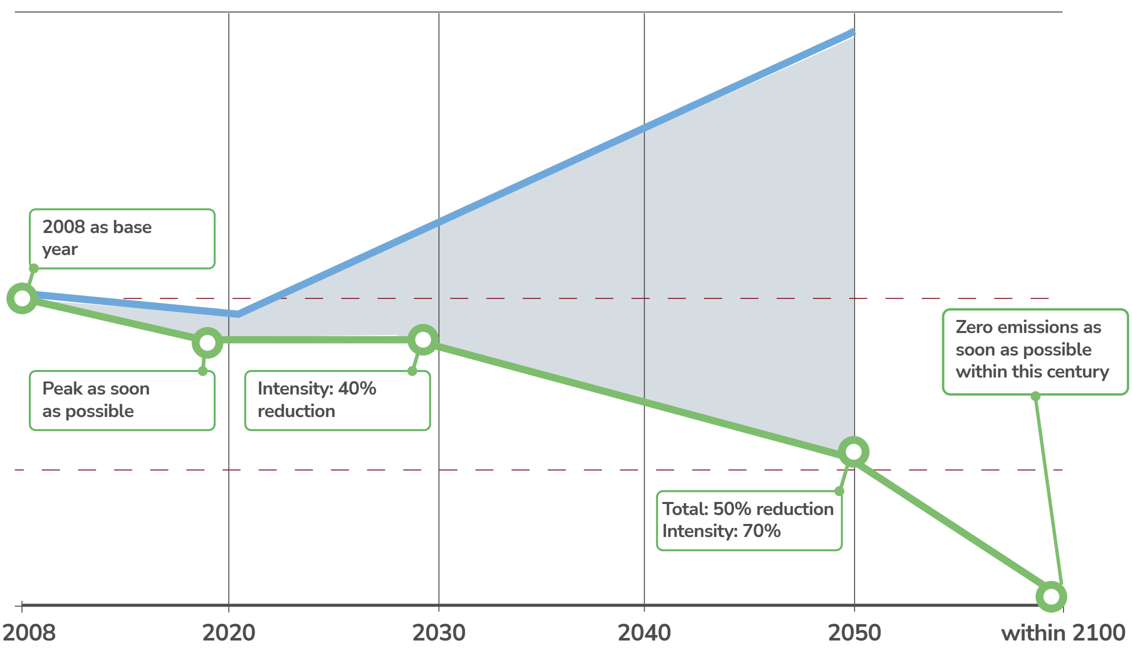
IMO INTERNATIONAL MARITIME ORGANIZATION

Next steps in the IMO roadmap:

- *November 2022* - the EEXI survey requirements will take effect
- *January 2023* - CII certification coming into effect

To tackle climate change, the IMO has established a series of actions to cut the GHG emissions from shipping. These actions will lead to a reduction in carbon intensity: compared to 2008, the $CO_2$ emissions will be cut by 40% by 2030, and by 70% by 2050. In addition, by 2050, the goal is to achieve a 50% reduction of the total annual GHG produced.
To achieve these goals, vessels will need to significantly reduce their output of carbon dioxide: in the short term, this will be reflected in a significant increase in vessel efficiency while in the long term this means a move from fossil fuels to alternative fuels, with vessels emitting zero carbon as the target.
The availability of carbon capture technologies will therefore a key role in reaching the targets, both in the short and long term.
The IMO actions to tackle climate change started in 2011 and, in the upcoming decade, additional measures will be introduced ahead of the 2030 target.

### IMO GHG targets




Total: Refers to the total amount of GHG emissions from international shipping. Intensity: Carbon dioxide ($CO_2$) emitted per ton-mile.
**Note that the business-as-usual emissions are illustrative, and not consistent with the emissions baseline used in our modelling.*

The short-term measures aim to achieve a reduction in carbon intensity, one of the initial IMO GHG strategies. This will be done by requiring all ships to calculate their Energy Efficiency Existing Ship Index (EEXI) following technical measures to improve their energy efficiency, and to establish their annual operational carbon intensity indicator (CII) and CII rating; the CII determines the annual reduction factor needed to ensure continuous improvement of the ship's operational carbon intensity within a specific rating level. However, there are many things a ship can do to improve its rating through various measures, such as hull cleaning; installation of hull appendages to improve overall efficiency of the hull movement through the sea water and adoption of air bubble lubrication systems in order to reduce drag; speed and routing optimization; installation of low energy light bulbs; installation of solar/wind auxiliary power for accommodation services and so on.

## EEXI improvement measures

| Description | Power limitation (% rel. to MCR) | Ship speed loss (% rel. to $V_S$) | Ship speed loss (%) |
|---|---|---|---|
| Engine power limitation | up to 50 | -21 | -37 |
| **Description** | **SFOC improvement** (%) | **Different $C_F$** (%) | **EEXI Improvement** (%) |
| Fuel change from MDO to LNG | 10 | 15 | 25 |
| **Description** | **Power reduction** (% rel. to $P_{ME}$) | **Ship speed reduction** (% rel. to $V_{ref}$) | **EEXI Improvement** (%) |
| Rotor sails (2 units) on Long Range 2 tanker | 4 | | 3,8 |
| Installation of shaft generator | 6 | 1,7 | 5,6 |
| Combination of both installations | 10 | 1,7 | 9,5 |
| **Description** | **DWT increase** (%) | **att. EEXI gain** (%) | **EEXI Improvement** (%) |
| Deadweight increase | 5<br>10 | 3,7<br>7,1 | 1,5<br>3,0 |
| **Description** | **Power reduction** (% rel. to P) | **Ship speed reduction** (% rel. to $V_{ref}$) | **EEXI Improvement** (%) |
| Energy saving device (e.g. PBCF, duct) | 1<br>4<br>7<br>10 | 0,3<br>1,4<br>2,4<br>3,5 | 0,3<br>1,3<br>2,3<br>3,3 |

Source: DNV - 2021

The current range of available measures often involves solutions which are difficult to implement without affecting the operational profile (e.g. EPL, SPL, etc.). Moreover, these can be expensive and technically challenging, for example when converting to LNG fuel. Other issues to take into account are the deadweight increase which is difficult to achieve, while significant GHG emission reduction is not very effective.

### EEXI and CII in short

**Attained Energy Efficiency Existing Ship Index (EEXI)**

The amendments to MARPOL Annex VI, adopted by Resolution MEPC.328(76) and due to enter into force on 1 November 2022, require new and existing ships of 400 GT with conventional propulsion systems to calculate the Attained EEXI which must be equal to or less than the required EEXI.

The EEXI indicates the energy efficiency of the ship with conventional propulsion systems compared to a baseline. Ships are required to meet a specific required Energy Efficiency Existing Ship Index (EEXI), which is based on a required reduction factor, expressed as a percentage relative to the Energy Efficiency Design Index (EEDI) baseline. The verification of the ship's Attained EEXI, based on an EEXI Technical File, will take place starting from 1 January 2023.

**Attained EEXI ≤ Required EEXI = (1-Y/100) × EEDI Reference line value**

*Where Y is the reduction factor for the required EEXI compared to EEDI reference line.*

In case of non-compliance with the requirement, modifications to the ship must generally be considered, regarding the power of main and auxiliary engines and capacity per reference speed. It is clear that many of those modifications play a significant role in reducing the commercial competitiveness of the ship.

**Annual operational Carbon Intensity Indicator (CII) and CII rating**

The attained annual operational CII of individual ships is the ratio of the total mass of $CO_2$ emitted to the total transportation carried out in a given calendar year. This gives a figure of the usage of the ship: the lower the CII, the more virtuous the ship. An operational energy efficiency performance rating should be annually assigned to each ship to which regulation 28 of MARPOL Annex VI applies, based on the deviation of the attained annual operational CII of a ship from the required value. The initial rating thresholds are set using 2019 as a base and will become stricter over time.

**Required annual operational CII = (1-Z/100) × $CII_R$**

*Where Z is the annual reduction factor; and $CII_R$ is the reference value.*

# Fuel Cells

## A sustainable approach to reach the 2050 IMO GHG targets

The new generation of Molten Carbonate Fuel Cells (MCFC) combine high efficiency clean power generation and carbon capture in the same equipment. Other advantages of such solutions are negligible pollution and low maintenance as there are no moving parts in the fuel cell. This technology can be also integrated with other Ecospray environmental solutions such as DeSOx, particle filters, and oxidation catalysts. Molten Carbonate Fuel Cells can be powered by methane (LNG, bio-LNG), hydrogen, ammonia, syngas and other fuels providing the reforming/cracking externally or directly inside the cell. This represents a sustainable and holistic approach to the development and implementation of a new generation of fuel cells.

# Molten Carbonate Fuel Cells,

## Explained

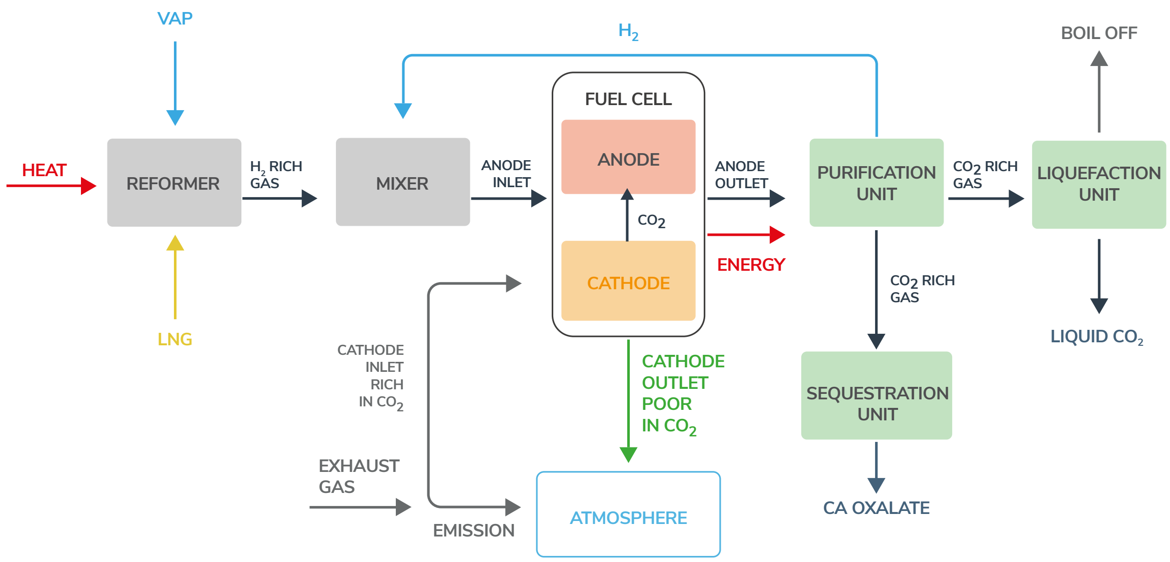
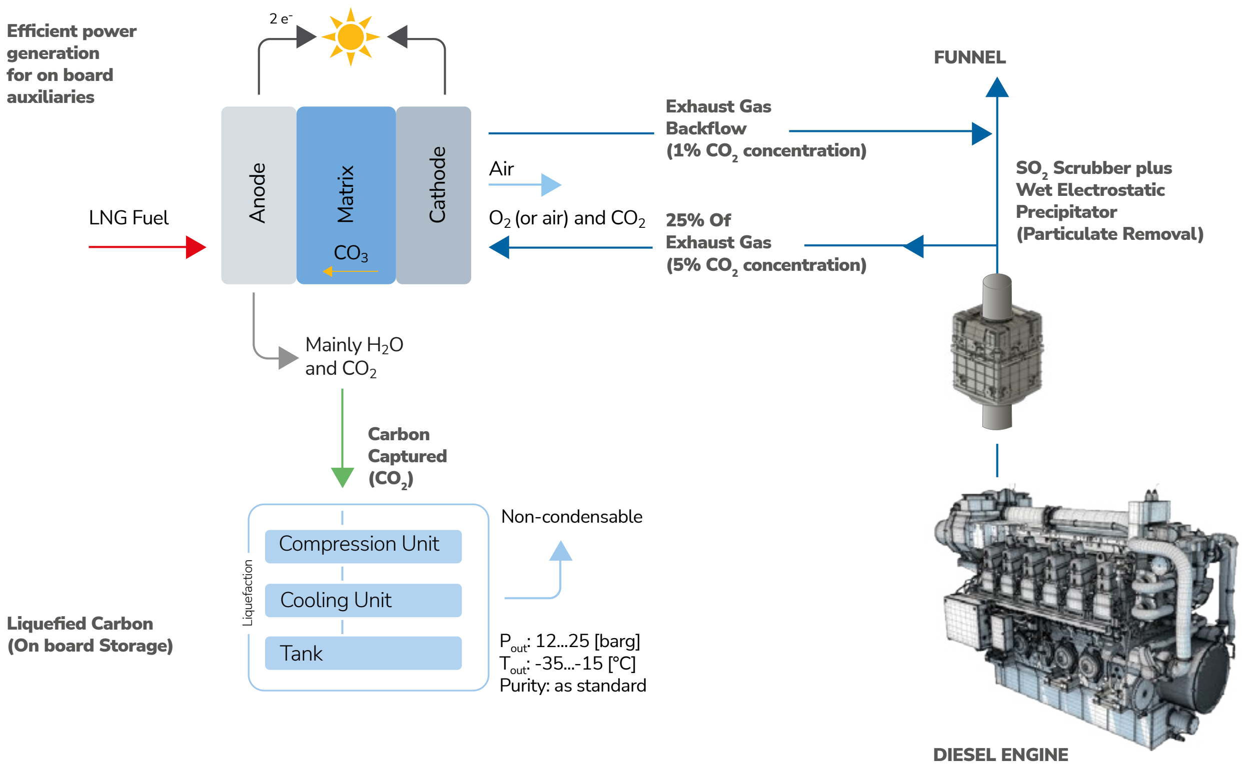


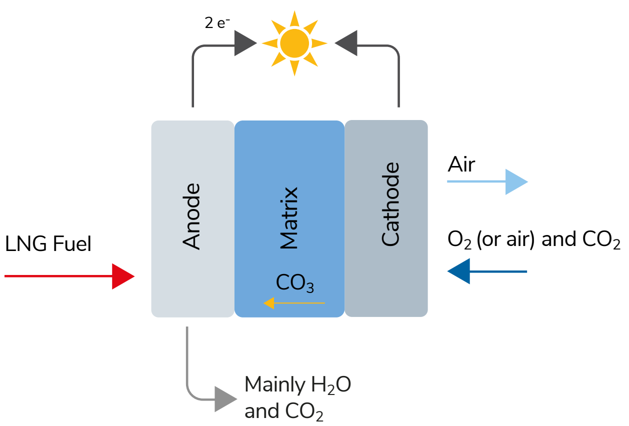

Figure A

Molten Carbonate Fuel Cells (MCFC) are based on a mixture of carbonate salts as electrolytes. The fuel cell needs to operate a high temperature (approx. 600°C) in order to melt the carbonate salt; only in liquid form the salts are capable, by diffusion, of exchanging carbonate ions, thus working as electrolytes.
As for all fuel cells, when activated, there are two basic reactions inside: oxidation at the anode and reduction at the cathode. These two reactions produce electrical current, which is the first key output of the fuel cell.
Specifically, in the MCFC, for the basic reaction to happen, the anode has to be fed with a gas rich in hydrogen, at a high temperature – to melt the carbonate ions and ensure they can work as electrolytes. The hydrogen oxidates in $H^+$ ions. The cathode, meanwhile, has to be fed with $CO_2$, to prevent the depletion of the carbonate ions formed due to the reduction of the oxygen bonded to $CO_2$ and migrating from cathode to anode in order to restore the electrical balance of the system.
When carbonates reach the anode, they react with $H^+$ ions forming carbonic acid ($H_2CO_3$) that then breaks down into $CO_2 + H_2O$ that are released into the outlet gas. This is the second key output and, because of this, the MCFC can conveniently be integrated into a carbon capture process.
Even if MCFC could be directly fed with natural gas, higher efficiencies are achieved with a preliminary reforming of methane to hydrogen. In *Figure A*, a thermal steam reforming process is shown; this step could integrate catalytic reforming or preferential oxidation of carbon monoxide to carbon dioxide, leading to further production of hydrogen.
Downstream of the fuel cell, residual hydrogen can be recovered, e.g., with membrane separation, and the concentrated $CO_2$ stream is then liquefied for onboard storage.

## On board MCFC applications




Source: Ecospray




Our new generation of Molten Carbonate Fuel Cells can significantly reduce the ship $CO_2$ emissions. Several options for the $CO_2$ storage, onboard and ashore are being studied.

- **Operating conditions**
  Cell Voltage: 0.6 – 1 V
  Current: 0-1500 A/m$^2$
  Pressure: 1 – 10 barg

- **Operating temperarure**
  600 – 700 oC Electrochemical Reactions
  $H_2 + CO_3^{--} \rightarrow H_2O + CO_2 + 2e^-$
  $CO_2 + ½\ O_2 + 2e^- \rightarrow CO_3^{--}$

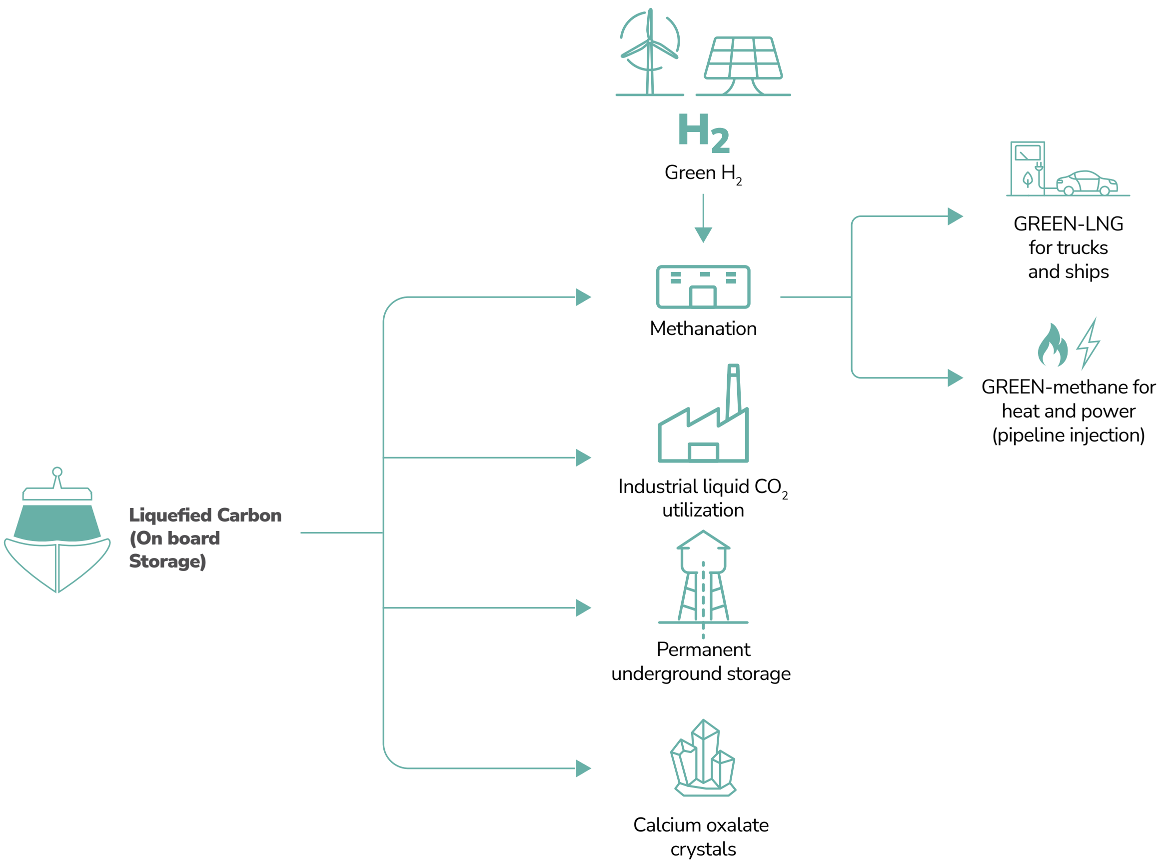
## $CO_2$ Liquefaction

$CO_2$ liquefaction is a cross-industry application that consists in the liquefaction of $CO_2$ through several sequestration technologies - biogas upgrading to biomethane systems, bio-LNG/ LNG, MCFC, amine absorption-based CC - into an industrial quality product. This solution supports the circular economy and decarbonization, increasing the sustainability of the entire production cycle with the goal of becoming a "carbon negative" process.
The $CO_2$ captured from the system is liquefied in a dedicated purification and liquefaction plant. The raw $CO_2$ coming into the system is pressurized through a multi-stage compressor and dried with molecular sieves for moisture removal to prevent the formation of ice in the subsequent stages of liquefaction. The compressed gas is then cooled using a heat exchanger and a chiller, and purified with dedicated drums and separators.
The output of the separator is a 99.5% concentrated $CO_2$, industrial-grade compliant.

## Carbon Capture Utilization and Storage

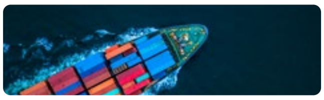
$CO_2$ liquefaction is one of the options Ecospray can provide. With the standard method, $CO_2$ is stored as a refrigerated liquid (-40°C) under pressure (15 barg). $CO_2$ is non-flammable, non-explosive and nontoxic, but due to the asphyxiation risk, precautions must be taken.
While liquefaction of $CO_2$ is a techology that is already available, other technologies for $CO_2$ sequestration are being studied. A research project on a low-cost $CO_2$ sequestration method is being carried out in collaboration with Turin University: this method consists of the use of a green reaction to trap the $CO_2$ in a stable crystalline phase (weddellite).

Another approach is $CO_2$ adsorption with lime milk. Lime milk is a suspension of calcium hydroxide in water with a solid content ranging from 10% to 30%. Calcium oxide reacts with $CO_2$ to form calcium carbonate. Calcium carbonate is only slightly soluble in water, so it will form a solid product. The suspension of calcium carbonate is harmless for the marine environment; indeed, limestone is a constituent of various marine organisms. The possibility of discharging the calcium carbonate suspension overboard is currently under evaluation; this could potentially be easily dissolved by the larger volume of seawater.



## Road to 2050: where are we?

**Q1-2021**
**MCFC**: process definition for marine applications



**Q2-2021**
**MCFC**: feasibility study for different types of ships

**Q3-2021**
**AMINE**: feasibility study for amine technology and lime milk technology

**Q4-2021**
**MCFC**: electrode chemical mix, production methodologies and quality control

**Q1-2022**
**MCFC**: stack geometry, thermofluid dynamics and selection of materials

**Q2-2022**
**AMINE**: class approval for onboard installation and tests - LAB 1 Alzano

**Q2-2022**
**MCFC**: new lab for fuel cell development and testing (Genoa, Italy)

CapLab
ELECTROCHEMICAL CELLS

**Q3-2022**
**AMINE**: Pre-assembled skid ready for onboard installation & on board test and first tests of lime milk technology

**Q4-2022**
**MCFC**: $CO_2$ liquefaction system and treatment for onboard storage

**Q4-2022**
**LIME MILK:**
start of onboard testing

**Q4-2022**
**MCFC**: marine engine exhaust gas pollution check for fuel cell compatibility (ULEV) – LAB 1 Alzano

**Q1-2023**
**MCFC:** Ultra-compact catalytic steam reforming reactor and ultra-compact heat exchangers for high temperature applications

**Q1-2023**
**LIME MILK:**
completion of onboard testing

**Q2-2023**
**MCFC:** pilot system installed in LAB 1 (power: 20 kW) – lab & testing

**Q2-2023**
**AMINE:** industrialization

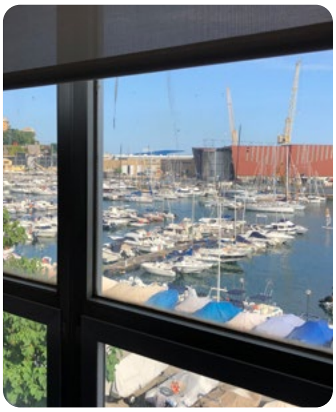
**Q3/4-2023**
**MCFC:** industrial pilot system installed on board (power 400 kW) – lab & testing

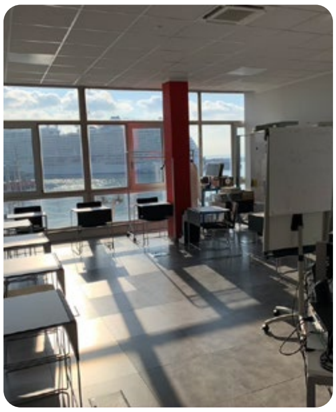
# **The new** CapLab

The CapLab laboratory was established jointly by Ecospray and the Department of Civil, Chemical and Environmental Engineering of the University of Genoa with the aim of developing electrochemical cells for $CO_2$ capture, the production of energy and the promotion of the hydrogen carrier. The CapLab will be opened in the coming months (in late spring) in Genoa, in the touristic port area.

CapLab ELECTROCHEMICAL CELLS FOR CARBON CAPTURE & ENERGY TRANSITION

Università di Genova





# **Single cell testing**

The single cell testing phase plays a key role in the MCFC development. In this phase, currently ongoing, different fabrication materials and chemical compositions are studied on a 10x10 cm single-layer cell. The current-voltage curves, resulting from testing, provide the possibility to compare the behaviors and the performance of the single cells with the target to select the most optimal one for the stack production.

# **Stack geometry study**

The fuel cell stack consists of a pile of single cells. The stack also includes bipolar plates, gas headers, seals and end plates, as well as the tensioning system.

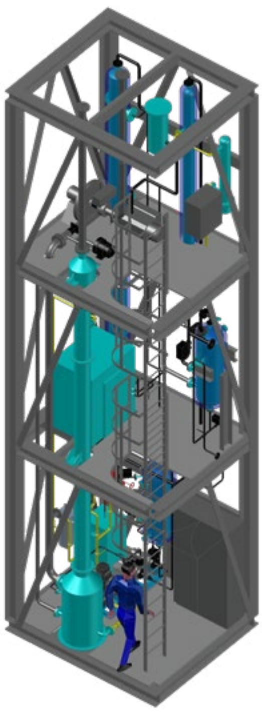
The power of a single cell is 0.5 kW; to reach higher power generation, the cells are stacked (300 cells) for a total output of 150 kW.

# **What's next** - coming soon

If MCFC is considered the right solution for a good number of applications, in certain cases – in light of different ship operational profiles, routes, available infrastructures, etc. – alternative technologies could be applied. For this reason, diverse solutions are under development to cover a wider range of necessities.

Ecospray is fully involved in the study and development of an amine absorption technology for CCS in marine onboard application. This solution is widely used for land-based applications and Ecospray is now working on the marinization of the technology, keeping an eye on monitoring the reduction in energy consumption.

$CO_2$ is absorbed by the amine solution and, during the process, the amine solution is regenerated by stripping the $CO_2$ out of it. Once separated, the $CO_2$ is then liquefied and stored in specific cryogenic tanks onboard.



Source: Ecospray

**In the next issue:**
"An in-depth look at amine technology"

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Via Circonvallazione, 14/14A
15050 Alzano Scrivia (AL) Italy
+39 0131 854611
marine@ecospray.eu
ecospray.eu