

NEWSLETTER

1st ISSUE



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Editorial



Welcome to the 1st newsletter of the NAUTILUS project. The first year of **NAUTILUS project coincides with the introduction of the European Union's ambitious strategy to make Europe a climate neutral continent by 2050 – The European Green Deal.** This vision encompasses all aspects of our society, how the energy is produced and used at the heart of it. The ambition of the project NAUTILUS aligns with

this vision. It aims to develop a highly efficient energy system for large passenger ships to curb their emissions of greenhouse gases and other pollutants, to comply with the targets of the International Maritime Organisation for 2030 and beyond. As local emission standards, both for CO₂ and pollutants in several regions in the EU such as Fjords are getting more stringent than the global targets, NAUTILUS also examines the possibility of fully sustainable energy solution for vessels.

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There are a variety of technologies available at different stages of maturity, from development to implementation to reduce emissions from ships. The consortium of NAUTILUS, with strong competences and experience in developing, integrating and operating marine power systems, has chosen to develop and test a hybrid power system consisting of the Solid Oxide Fuel Cell (SOFC) and battery. The technological challenges of scale-up, optimal design, efficient hybridization, dynamic power demand response and safety are addressed by the project.

NAUTILUS energy system will be fuelled at first with Liquefied Natural Gas (LNG) instead of heavy fuel oil. Using LNG with a highly efficient energy system is targeted to save 40% of CO₂ emissions. Having in the sight the EU 2050 goal of 70% CO₂ reduction, our envisaged step includes the testing of the novel energy system with the selected synthetic fuels.

Overview of the NAUTILUS Project

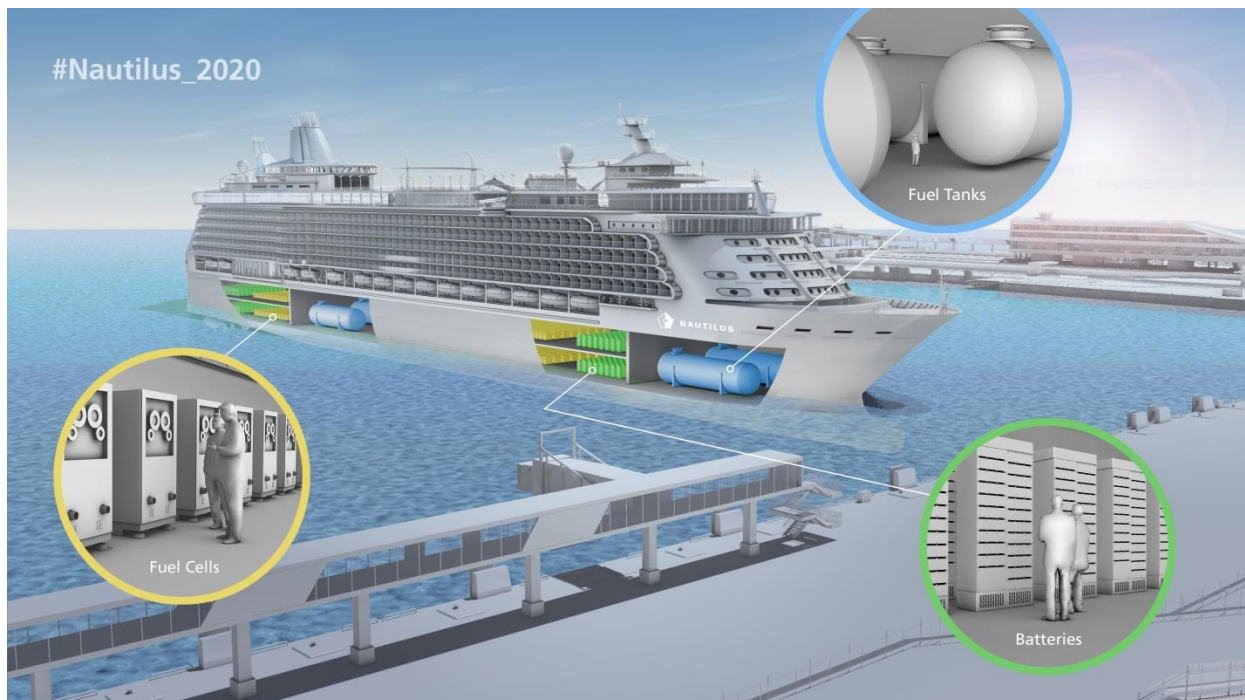
NAUTILUS is an EU funded project, which focuses on improvement of the environmental footprint of passenger and cruise ships. These ships have to comply with emission cuts set by the Paris Agreement, regulations of the International Maritime Organization, and recent goals of the European Green Deal. IMO has introduced a target of 40% reduction of CO₂ by 2030 compared to 2008 and pursuing 70% reduction by 2050. There is also societal pressure on decreasing the emissions of passenger ships because they spend more than 50% of their operation time docked on ports. Travellers, as well as local residents, are demanding a clean and smoke-free environment.

What are NAUTILUS project goals?

- ✦ Reduce greenhouse gas emissions by 50%
- ✦ Reduce other pollutants to nearly unmeasurable level
- ✦ Improve dynamic capacity and modularity of the novel power system
- ✦ Allow fuel flexibility that will lead to further emission reduction (IMO 2050 targets)

How will be these goals reached?

- The first pillar is dedicated to the cruise ship integration of the modular Solid oxide fuel cell (SOFC)-battery genset and evaluation of the ship's energy performance.
- The second pillar focuses on research and development activities of the modular genset system engineering and development of the **experimental proof of concept**. Extensive simulation, modelling and experimental activities are undertaken and connected to the development of a unitized control strategy of the modular genset that combines the control system of the SOFC system and battery management system.
- The third pillar aims at the design, engineering, procurement, assembling, construction and **testing of a genset demonstrator**.



NAUTILUS Consortium

The project consortium consists of key actors in maritime passenger transport including ship operators, shipbuilders, a marine engine builder, a marine regulatory company, as well as technology developers supported by research organisations. The consortium of the project consists of 9 industrial

partners and 6 research organisations from 9 EU countries. Global leaders in the maritime industry and the fuel cell & hybrid energy technologies are connected, covering a clear and strong value chain.

The project is coordinated by [Deutsches Zentrum für Luft – und Raumfahrt](#).

NAUTILUS Consortium:

CM	Carnival Maritime	Germany
DLR	Deutsches Zentrum für Luft – und Raumfahrt	Germany
EPFL	Ecole Polytechnique Fédérale de Lausanne	Switzerland
GG	GRANT Garant	Czech Republic
CdA	Chantiers de l'Atlantique	France
LR	Lloyd's Register EMEA	Germany/UK
LU	Lunds Universitet	Sweden
MAN	MAN Energy Solutions	Germany
MW	Meyer Werft	Germany
RWTH	Rheinisch-Westfälische Technische Hochschule Aachen	Germany
RUG	Rijksuniversiteit Groningen	The Netherlands
SP SA	SOLIDPower SA	Switzerland
SP_SPA	SOLIDPower SPA	Italy
TUD	Technische Universiteit Delft	The Netherlands
VTT	Teknologian tutkimuskeskus VTT	Finland



Progress in the Technology Part

Requirement Analysis – Work Package 2

In the **NAUTILUS** project, we are developing a new concept for providing electricity and heat to cruise ships which is needed for propulsion and on-board energy demands.

Development of new technologies often times starts with the analysis of the actual problem and the definition of requirements that have to be met in order to solve a problem. This includes careful evaluation of boundary conditions.

Analysis of requirements is the main focus of work package 2 (WP 2) of the NAUTILUS project. This work is led by the **MAN Energy Solutions**.

Our analysis started with an investigation about **available technologies** which can be used for our application. We researched different types and characteristics of **fuel cells** and batteries from existing literature resources or directly from producers of these technologies. Possible future developments were also included. This study set the general frame of what can be technically achieved with these technologies.

Further information about the “Comparison of Technologies for on-board power supply system of cruise ship” to be found on the [NAUTILUS project web page](#).

In the second part of this work package, we analysed key **technical requirements** for cruise ship power systems for **two different cruise ship sizes**. This includes an investigation of how much power at what point in time is actually needed during the operation of the ship. How quickly does this power demand change e.g. because the ship starts leaving a port? Which regulatory requirements have to be met for example in terms of emissions? What are

acceptable maintenance intervals and how much redundancy is needed in order to ensure the safe and stable operation of the ship? What are the lifetime costs of different technologies and how is this influenced by the high efficiency that fuel cells can offer? What is the space demand of fuel cell-based systems? How do passengers see fuel cell systems and would they benefit from lower vibrations and emissions? All these questions were addressed to come up with recommendations for the system design.



Safety requirements were addressed in a separate part of this work package as it is a key aspect when operating cruise ships. Failure of the on-board power supply system can have a severe impact on the safety of passengers and crew. For example, one key requirement is the **“safe return to port”**, which has to be ensured in case of technical failure. Safety related aspects and requirements were investigated and summarized in a separate report.

The results of this work package will be used as a base for designing the NAUTILUS power system. The work will thus support the development of suitable power systems for cruise ships.

Genset System Engineering & Proof of Concept – Work Package 3

The third work package (WP 3) is led by the coordinating institution - Deutsches Zentrum für Luft – und Raumfahrt (DLR, German Aerospace Centre). From the design of the hybrid energy system to the development of a virtual simulator, this work package comprises the **core engineering of the system** that can supply the ship's energy demand in the NAUTILUS concept.

In the first year, the process has been delineated by partners from the Delft University of Technology (TUD) and the University of Groningen (RUG) in the form of a first process flow diagram. This diagram shows the principle connection of the used components, the main equipment and the general material and energy flows. This document is based on the operating scenarios that have been determined in work package WP 2 (Requirement analysis). Optimal thermal management is instrumental for the overall efficiency of the process. Therefore, partners from the École polytechnique fédérale de Lausanne (EPFL) will use this first process flow diagram as a basis for an optimization of the heat exchanger network. The technology approach in the scope of NAUTILUS is a highly

efficient SOFC coupled to a battery. Hence, activities for validation of this hybrid system are in progress. The fuel cell component will be assembled and tested by partners from SOLIDpower. Hybridizing the SOFC with batteries will enhance the capabilities of the system to respond to fast transient energy demand. That is why a Li-ion battery will be provided by partners from MAN. The hybrid system will be assembled as a Proof-of-Concept and tested in a system-relevant testing facility at DLR.

The system has to be controlled. That is why partners from DLR and RWTH-Aachen University started to develop models for simulating its behaviour as a basis for a control algorithm. This algorithm will be further developed under WP 5 (Control strategy and grid connection). As a result of WP 3, **the hybrid energy system will be validated and a tool (virtual genset simulator) will be developed** by partners from VTT. It will be **incorporated into the energy simulation of cruise ships by the ship operators**. Finally, the ship operators can apply this tool to improve the design.



Figure 1: Test rig for the build-up of the PoC at DLR

Control Strategy and Grid Connection – Work Package 5

A control strategy for the operation of the hybrid **Genset propulsion system consisting of a fuel cell system and a battery system has to be developed.** This is main focus of the work package 5 (WP 5) of the NAUTILUS project. This work is led by the Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen University). The control strategy is part of the unitized control unit of the hybrid genset system and shall perform the energy management for the whole ship's control unit.

In the course of developing the control system, the drive components are simulated in a model for operating the cruise ship. For this purpose, measurements on a battery module were used to obtain an initial parameterization of the battery model. The performance of the initial battery model was validated with actual measurement data from a battery module.

Additionally, **cruise and load profiles were obtained from project partners.** The profiles for different cruise ship sizes will be utilized within the simulation environment to represent a realistic scenario of a cruise in the simulation. This allows a power distribution between the drive components to be developed in the simulation model under realistic

conditions.

Furthermore, work has begun on the Battery Management Unit (BMU), which is additional hardware. BMU implements algorithms for predictions of signals - such as the available power of the battery system. At present, the BMU has been developed as a model. In the future, the BMU will be run on electronics.

To further develop the control system and electronics for the battery systems, the models of the battery and the powertrain will be refined and thus improved. Subsequently, a **first design of the control system will be realized in the simulation environment.** Only with accurate models that replicate real components with a high degree of accuracy can a well-functioning control system be developed.

In the further course, all models will be ported to real-time capable hardware and prepared for test bench operation. The control of the drive components is developed for the different development stages of the test bench (Proof of Concept and Demonstrator).

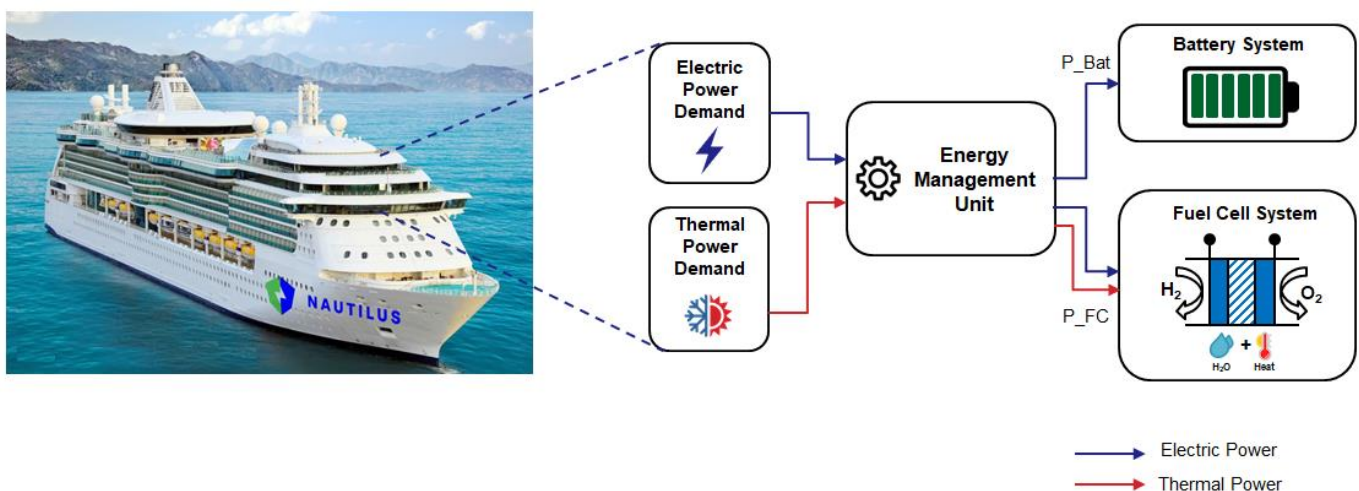


Figure 2: Energy Management Unit of a ship

Technology Impact Analysis - Work Package 7

In order to diminish emissions produced by the shipping industry the overall tendency is to replace conventional fossil fuels with alternatives. The main fuel for the NAUTILUS project is compressed LNG but other alternative fuels have to be examined as well. The performance of the hybrid SOFC genset with alternative fuels and its impact on cruise ship operation through techno-economic, emission and life cycle are the core of work package 7 (WP 7) led by the Technische Universiteit Delft.

A fuel flexible genset ensures emission compliant operation throughout the lifetime of the ship with both existing and potential future bunker fuels. As there is a variety of alternative fuels, a long list of future fuels was prepared in the first step and evaluated on a large number of criteria, including production capacity, volumetric and gravimetric energy density, technology maturity, safety, fuel cost and last but not least, by environmental impact. An overview of the selected future fuels is shown in the Table below. Next to the LNG, which is the fuel of choice in the project, **bio methanol, synthetic diesel, ammonia and hydrogen are shortlisted for the further analysis.**

Genset models for the proof of concept fuelled with LNG are developed in WP 7. These models are adjusted to analyse the performance of the genset with **bio methanol and synthetic diesel, ammonia and hydrogen in order to** identify any additional

components required to meet the on-board electricity and heat demands of the ship. The results of this performance analysis will be used in the techno-economic analysis and to make recommendations for the engineering of the genset system and improve the fuel flexibility of the genset.

A literature survey on the emissions of the currently used marine internal combustion engines (ICEs) and of systems based on solid oxide fuel cell (SOFC-based systems) is carried out in parallel. Detailed emission measurement will be carried out on the demonstrator developed later in the NAUTILUS project.

The results of both genset performance modelling and emission measurements will finally be used in a comprehensive life cycle analysis to evaluate the overall environmental impact of an integrated marine energy and propulsion system based on the developed SOFC-battery hybrid genset. The NAUTILUS project expectance is that the developed system will cut greenhouse gas emissions by 50% and all other diesel engine exhaust gas emission components almost entirely but in order to meet the IMO target beyond 2030 – 70% CO₂ reduction by 2050 alternative fuels have to be introduced aside to improvement of the energy efficiency.

More information about the “Fuel Shortlist Analysis” to be found on the [NAUTILUS project web page](#):

Table of Selected Fuels		
Short list	Fuel	Storage Technique
LNG (main fuel of NAUTILUS)	Liquified Natural Gas	Cryogenic, - 162 °C
MeOH	Methanol	Liquid, Ambient temperature
FT D	Fischer-Tropsch Diesel	Liquid, Ambient temperature
NH3	Ammonia	Compressed 10 bar
LH2	Hydrogen	Cryogenic, - 253 °C

NAUTILUS News

Participation on Events

Even though the direct presentation of the NAUTILUS project was complicated due to the pandemic situation and travel restrictions, we have successfully presented the project at the 2nd LEC Sustainable Shipping Technologies Forum, online conference organised by the [Large Engines Competence Center](#) (LEC) together with [Hamburg Port Authority](#) and in cooperation with [Fraunhofer CML](#).



The LEC Sustainable Shipping Technologies Forum (27th - 28th April, 2021 online)

More: <https://www.shippingforum.at/>

The LEC Sustainable Shipping Technologies Forum aims to foster the exchange of ideas, to harness

synergies, to promote co-operations and to network relevant actors in the shipping sector for an emission-free future. Main topics of the event were: (i) Green ports & infrastructure, (ii) Ship efficiency technologies, (iii) Advanced propulsion & fuels, (iv) Ship emission monitoring & compliance. The NAUTILUS project was represented by **Dr. Asif Ansar, Head of High Temperature Systems and Processes group at the DLR – Deutsches Zentrum für Luft – und Raumfahrt** Centre. Dr. Ansar as a coordinator of the NAUTILUS project gave a speech in the third session focusing on advanced propulsion systems and fuels. His presentation focused on a paradigm shift in on-board energy systems and in marine fuels. This shift is essential for the reduction of emissions from waterborne transport, compliance with the IMO strategy and regulations of the Emission Control Areas (ECAs).

*The presentation "**Electrochemical processes and energy systems towards step-wise emission reduction of the marine transport**" can be downloaded from the [NAUTILUS project web page](#).*

Where Can You Meet Us?

The NAUTILUS project will be represented at various events in the forthcoming project year. The plan is subject of change depending on the actual COVID

2021

- 8th -10th September, **Seatrade Europe 2021 - Cruise & River Cruise Convention**, Hamburg, Germany
A fair gathering major players from the world's leading cruise and river cruise lines market.
- 27th -30th September, **Seatrade Cruise Global**, Miami, USA
New trends and solutions for cruising professionals from across the globe.
- 5th November, **Annual Aerosol Science Conference**, UK/Ireland
A forum for aerosol scientists from both academia and industry enabling to network and share knowledge.
- 9th November, **Symposium on ship emissions and air quality exposure at the Consortium for Aerosol Science and Technology (CCAR)**, Lund, Sweden



situation, which is hard to predict. At the moment of we are committed to present the NAUTILUS project to the public at these events:

2022

- 28th – 30th March, **Battery Conference 2022**, Münster, Germany
Battery Conference brings engineers and scientists from the entire field of battery technology together.
- 25th – 29th April 2022, **Hydrogen+Fuel Cells EUROPE at HANNOVER MESSE 2022**, Hamburg, Germany
The main topics at Europe's largest hydrogen and fuel cell event will be the storage of renewable energy and mobile and stationary fuel cell applications. In two forums, visitors will have the opportunity to inform themselves about these fascinating technologies.
- 21st – 23rd June, **Electric & Hybrid Marine Expo Europe**, Amsterdam, The Netherlands
The International Exhibition of Electric and Hybrid Marine Charging and Propulsion Technologies and Components
- 5th – 8th June, **European SOFC & SOE Forum**, Lucerne, Switzerland

NOTE: As the COVID situation may change our event participation in autumn 2021 /spring 2022- this time schedule may have been subject of change. We will inform you about our participation on events via our [project web page](#) and on our social media profiles at [LinkedIn](#) and [Twitter](#).

Articles about the NAUTILUS Project

The Motorship has been the magazine for senior marine engineers since 1920. The main audience are specialists and professionals from ship owners and operators to ship builders, naval architects and equipment suppliers. The Motorship magazine has published an article by Wendy Laursen about the NAUTILUS project called **“Modularity brings efficiency to hybrid fuel cell concept”**. The article

provides a short and comprehensive summary of the project.

The whole article can be found here:
<https://www.motorship.com/news101/alternative-fuels/modularity-brings-efficiency-to-hybrid-fuel-cell-concept>

Our Cooperation with Complementary Projects and Initiatives

The NAUTILUS project has a list of partners that have similar interests: mainly focused on reduction of emissions from ship industry, compliance with IMO targets, technology improvement of marine energy systems, increasement of energy efficiency.

AIRCOAT



AIRCOAT is a **Horizon 2020** EU funded project promoting a passive air lubrication technology with the potential to revolutionise the ship-coating sector.

More: www.aircoat.eu

The Large Engines Competence Center



LEC is one of the world's leading research institutions for large engine technologies and develops innovative solutions for sustainable energy and transport systems.

More: www.lec.at

Regular update on NAUTILUS partnership on the NAUTILUS [project web page](#).

On the Way to Green Maritime Transport

✦ 2020 fuel quality targets not filled despite 3.7% drop in greenhouse gas intensity since 2010

In November the Commission adopted its 2018 Fuel Quality Report based on the data submitted by EU countries. According to the data provided, the average greenhouse gas intensity of fuels in the 28 reporting Member States had fallen by 3.7% compared to the 2010 baseline. The year-on-year progress achieved compared to 2017 was limited to a 0.3% decrease. Progress varied greatly across Member States, but almost all need to take swift action to meet the 2020 target of 6%. [More](#)

✦ European Commission published guidelines for Autonomous and Sustainable Ships and Shipping

In November the European Commission published the EU Operational Guidelines on trials of Maritime Autonomous Surface Ships clarifying the roles of authorities and applicants and providing guidance for assessments when facing Maritime Autonomous Surface Ships (MASS) trials, including risk assessments. [More](#)

✦ EU submitted new greenhouse gas emissions reduction target to UNFCCC

Following the European Council's endorsement of a new and more ambitious target to reduce the EU's greenhouse gas emissions by at least 55% by 2030 from 1990 levels, the EU and its 27 Member States have in January 2021 formally submitted this target as their new nationally determined contribution (NDC) under the Paris Agreement. [More](#)

✦ Report on EU-wide alternative fuels infrastructure deployment

In March 2021, the European Commission published a report to the European Parliament and the Council on the application of Directive 2014/94/EU on the deployment of alternative fuels infrastructure (AFID). This report presents the results in implementation of the AFID and the development of markets for

alternative fuels and their infrastructure. The report states that in the area of electric recharging, large parts of the TEN-T core network do not have recharging points installed every 60 km as recommended. This is equally true for other alternative fuels infrastructure, especially for waterborne transport. In addition, maritime transport and inland navigation will also benefit from further common technical specifications to facilitate and consolidate the entry on the market of alternative fuels, especially in relation to fuel supply for electricity and hydrogen. [More](#)

✦ A new EU Strategy on Adaptation to Climate Change

In March 2021 the European Commission adopted a new European Union's Strategy on Adaptation to Climate Change, setting out the pathway to prepare for the unavoidable impacts of climate change. [More](#)

✦ Developing a sustainable blue economy in the European Union

In May 2021 the European Commission proposed a new approach for a sustainable blue economy in the EU for the industries and sectors related to oceans, seas and coasts. A sustainable blue economy is essential to achieving the objectives of the European Green Deal and ensuring a green and inclusive recovery from the pandemic. Detailed agenda of the blue economy will cover these targets: (i) Achieve the objectives of climate neutrality and zero pollution notably by developing offshore renewable energy, by decarbonising maritime transport and by greening ports. A sustainable ocean energy mix including floating wind, thermal, wave and tidal energy could generate a quarter of the EU's electricity in 2050. Ports are crucial to the connectivity and the economy of Europe's regions and countries and could be used as energy hubs; (ii) Switch to a circular economy and reduce pollution; (iii) Preserve biodiversity and invest in nature; (iv) Support climate adaptation and coastal resilience; (v) Ensure

sustainable food production; (vi) Improve management of space at sea. [More](#)

✦ Zero pollution action plan for air, water and soil

In May 2021, the European Commission adopted the [EU Action Plan: "Towards a Zero Pollution for Air, Water and Soil" \(and annexes\)](#) - a key deliverable of the European Green Deal. The zero pollution vision for 2050 is for air, water and soil pollution to be reduced to levels no longer considered harmful to health and natural ecosystems. This is translated into key 2030 targets to speed up reducing pollution at source. These targets include: (i) improving air quality to reduce the number of premature deaths caused by air pollution by 55%; (ii) improving water quality by reducing waste, plastic litter at sea (by 50%) and microplastics released into the environment (by 30%); (iii) improving soil quality by

reducing nutrient losses and chemical pesticides' use by 50%; (iv) reducing by 25% the EU ecosystems where air pollution threatens biodiversity; (v) reducing the share of people chronically disturbed by transport noise by 30%, and (vi) significantly reducing waste generation and by 50% residual municipal waste. [More](#)



Calls for Proposals for Green Maritime Transport

- ✦ Coordination of large-scale initiative on future battery technologies (Batteries Partnership). [More](#)
- ✦ Next generation technologies for High-performance and safe-by-design battery systems for transport and mobile applications (Batteries Partnership). [More](#)
- ✦ Manufacturing technology development for solid-state batteries (SSB, Generations 4a - 4b batteries) (Batteries Partnership). [More](#)
- ✦ Advanced high-performance Generation 4a, 4b (solid-state) Li-ion batteries supporting electro mobility and other applications (Batteries Partnership). [More](#)
- ✦ Hyper powered vessel battery charging system (ZEWT Partnership). [More](#)
- ✦ Proving the feasibility of a large clean ammonia marine engine (ZEWT Partnership). [More](#)
- ✦ Enabling the safe and efficient on-board storage and integration within ships of large quantities of ammonia and hydrogen fuels (ZEWT Partnership). [More](#)
- ✦ Innovative on-board energy saving solutions (ZEWT Partnership). [More](#)
- ✦ Assessing and preventing methane slip from LNG engines in all conditions within both existing and new vessels (ZEWT Partnership). [More](#)
- ✦ Enabling the full integration of very high power fuel cells in ship design using co-generation and combined cycle solutions for increased efficiency with multiple fuels (ZEWT Partnership). [More](#)
- ✦ Exploiting renewable energy for shipping, in particular focusing on the potential of wind energy (ZEWT Partnership). [More](#)
- ✦ Transformation of the existing fleet towards greener operations through retrofitting (ZEWT Partnership). [More](#)
- ✦ Innovative energy storage systems on-board vessels (ZEWT Partnership). [More](#)
- ✦ Computational tools for shipbuilding. [More](#)
- ✦ Next generation of renewable energy technologies. [More](#)
- ✦ Carbon-negative sustainable biofuel production. [More](#)

NAUTILUS Project Data

PROGRAMME:	Horizon 2020 Call: H2020-MG-2018-2019-2020
TOPIC:	LC-MG-1-8-2019 Retrofit Solutions and Next Generation Propulsion for Waterborne Transport
TYPE OF ACTION:	RIA
DURATION:	48 months, (1 July 2020 – 30 June 2024)
PROJECT BUDGET:	€ 7 892 362.50
CONSORTIUM:	15 partners from 9 European countries
COORDINATOR:	Deutsches Zentrum für Luft – und Raumfahrt, DLR

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