Summary description of project context and objectives

Biofouling has profound effects in different branches of maritime activities. It is the major cause for maintenance expenses of any (partially) submerged man-made surface, including ship transport, buoys, aquaculture, but also membrane bioreactors and desalination units, power plants' cooling water systems and oil pipelines. It poses also a significant problem for all the aquaculture industry, the broadest and the most documented impact being in marine fish aquaculture. The settlement of marine invertebrates on the hulls of ships results in increased erosion, reduction of speed, increased fuel consumption and therefore increased air pollution and CO_2 production.

Photo: TAU

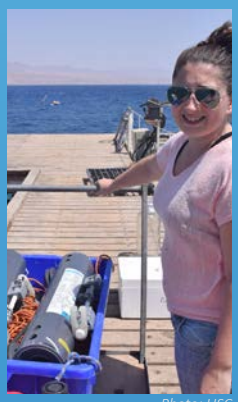

Photo: USC

Photo: Jotun

The main goal of the BYEFOULING project, supported in the framework of the Ocean of Tomorrow by the European Commission, is to design, develop and upscale novel low toxic and cost-efficient environmentally friendly antifouling coatings with enhanced performance compared to currently available products. The approach in BYEFOULING is to tackle different stages of the biofouling process using innovative antifouling agents, covering surface-structured materials, protein adsorption inhibitors, quorum sensing inhibitors, natural biocides and microorganisms with antifouling properties. Encapsulation of the innovative compounds in smart nanostructured materials will be implemented to optimize coating performance and cost all along their life cycle. A proof-of-concept for the most promising candidates will be developed and demonstrators will be produced and tested on fields.

The specific objectives of BYEFOULING are:

- obtain coatings with extended service life
- reduce VOC content in coating formulations
- reduce fuel costs due to drag reduction in maritime transportation and fishing vessels
- increase operation life of floating devices
- reduce fish mortality as a result of conventional biofouling processes and respective control measures
- reduce maintenance costs

The project is organized in 8 work packages (WP) and is running from December 2013 to November 2017. BYEFOULING combines a multidisciplinary consortium involving 19 partners from SMEs, large companies, research organisations and universities in Europe, able to develop a full production line for new antifouling coatings. In **WP1**, the project is coordinated and directed according to a work plan. In **WP2**, novel compounds, development of interfacial microstructures and preparation and growth of antifouling microorganisms are under development. In **WP3**, different tools are used to incorporate the new antifouling approaches into coating formulations, including encapsulation to protect compounds from the coating matrices and to enable controlled release of active species, preparation of functional fillers with hydrophobic and biocide-active functional groups, and development of waterborne coating formulations. In **WP4**, assessment of antifouling performance and benchmarking of the obtained systems with commercial and state-of-art technologies are carried out. Ecotoxicity measurements are performed to investigate the effect of the developed materials in the ecosystems. In **WP5**, relevant parameters for application of coating formulations in subsequent stages are under testing. In addition, fundamental studies on adhesion of fouling organisms and effects of fouling on biocorrosion are under investigation. In **WP6**, reliable methods for evaluation of drag resistance of vessel hull coatings and for application of holistic and comprehensive assessment tools such as Life Cycle Assessment (LCA) are under development. In **WP7**, demonstration activities will be performed aiming at preparing three types of demonstrators, specifically for ships, aquaculture and buoys. To obtain enough paint and related components, up-scaling of the most promising technologies will be implemented. In **WP8**, the results will be disseminated and exploited. SMEs and industrial partners will in particular use the developed technology to address new market areas.

Description of work performed and main results

In **WP1**, an internal website (eRoom) was created for BYEFOULING partners with detailed information on the project. A routine for EB/MST meetings and reporting is implemented. The kick-off, 6M, 12M and 18M meetings were held for reporting results and discussing technical and management activities. The 6M, 12M and 18M reports (financial and technical) have been assessed and reviewed by the MST. Dissemination has been realised according to a revised decision procedure for publications. A project ethics committee is established to follow research activities on living animals.

Photo: USC

In **WP2**, studies on surface structuration, protein adsorption inhibitors, quorum sensing inhibitors (QSI), natural biocides and living active species were carried out. For surface structuration, the feasibility of obtaining double wavelength-wrinkled surface with labyrinth morphology has been showed. In the field of biomimetic surface composition, several compounds have been extracted from different marine organisms, having potential antifouling properties. With respect to protein adsorption inhibitors, two types of systems are being studied: peptide-like and poly-zwitterionic materials. Different QSI compounds/ extracts were tested and a large number of novel marine bacteria with wide-spectrum enzymatic QSI activity has been already identified. In the field of Living Active Species, freeze-dried cells and endospores of different bacteria strains have been produced.

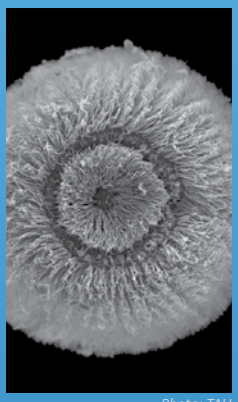
Photo: TAU

WP3 partners have focused on the synthesis and characterization of nanostructured inorganic, organic and hybrid materials that can be used as reservoirs for the encapsulation of active species, including dormant microorganisms with antifouling properties. The surface functionalization of the synthesized nanomaterials has been investigated in order to improve dispersion in polymeric matrices. Synthesis of carbon nanotubes (CNTs) with specific characteristics and different fillers with antifouling and hydrophobic functionalities were also performed. Finally, screening paints and reference antifoulants have been produced and sent to several partners to apply the first coatings for field and mesocosm tests.


Photo: SMT

In **WP4**, normalization of procedures to characterize antifouling systems was completed. Protocols have been written for laboratory tests on anti-microfouling efficacy, anti-macrofouling efficacy, mesocosm efficacy tests, field efficacy tests of the antifouling paint prototypes and ecotoxicity tests. Free compounds developed in WP2 and intermediate materials prepared by WP3 partners were all tested. Results on antifouling activity in lab tests were communicated to other WPs and the first field tests have been launched with the most promising BYEFOULING systems developed so far.

In the frame of **WP5**, data about surface characterization were collected. With respect to fundamental studies, partners have set up experimental characterization techniques and cultures of bacteria have started to produce biofilms. Most importantly, in conjugation with WP2, WP3 and WP4, different coating formulations were prepared and the first field tests have been launched.

In **WP6**, activities related to the development of the mathematical models for drag reduction prediction and activities related to LCA were performed. Models for studying self-polishing paints have been used, flow of fluids has been simulated and experimental designs studied to obtain relevant experimental data. Furthermore, the first results on LCA have been obtained.

In **WP7**, planning activities on demonstrator design and exposure locations both for ships, aquaculture and for satellite buoys have started.

In **WP8**, several dissemination activities have been realised, including organization of training courses, short visits and specific tools (public website and newsletters) for dissemination. The first BYEFOULING workshop was organised by USC, in collaboration with TAU (leader of WP8). A first draft of exploitation plan is also available.

Expected final results and potential impacts

The BYEFOULING project addresses high volume production of low toxic and environmentally friendly antifouling coatings for mobile and stationary maritime applications. The technology will fulfil the coating requirements as a result of the incorporation of novel antifouling agents and a new set of binders into coating formulations for maritime transportation and fishing vessels, floating devices and aquaculture. Readily available low toxic and cost-effective antifouling coatings will increase the efficiency of maritime industry and be the enabling technology to realize new products.
The potential impacts of the project can be divided into internal and external ones. Internally, academic partners (universities, research institutes) participating in BYEFOULING will form young researchers in an interfacial field where knowledge on biology, marine sciences, chemistry, physics, materials science and engineering, and coating technology come into play to generate environmentally friendly and at same time high performance products. This is a strong positive point when considering high-level education and competitiveness of jobs in the global market. In addition, the generated knowledge will be reflected upon publications in journals of high impact factor which is always one of the main factors for assessment of public institutions applying for funding supports. From an industrial perspective, the involved SMEs and large industries have a unique opportunity to establish transnational networking developing high-level products that can be disruptive in the global market.

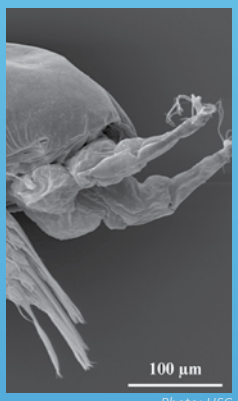

Photo: USC


Photo: USC

Externally, the impact of BYEFOULING can be detailed for different sectors. In the ship transport sector, BYEFOULING will offer more efficient and less toxic antifouling coatings, the operation and lifecycle costs will be significantly reduced, thereby increasing the efficiency and competitiveness of the ship transport industry. Furthermore, the project will contribute to reduce the negative impacts on the marine environment and CO2, NOx and SOx emissions. In the aquaculture sector, BYEFOULING products will improve the performance of marine operations, with better growth rates, improve water quality and provide a better control of disease vectors, reduce costs associated with copper waste disposal, enable lighter structures and improve resistance towards extreme weather and enhance the viability towards more stringent regulations on the use of biocides.


Photo: Jotun

BYEFOULING provides new societal insights by taking into account national and transnational objectives within the EU for the future. Specifically, it pertains to several aspects of what is termed "blue growth". BYEFOULING thus targets a new generation of materials derived directly from marine renewable resources; while the impact of antifouling coatings generated in the project will profoundly affect industrial activities directly related to the marine realm.