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 finfish 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 CO2 production.

Photo: TAU

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 are under implementation to optimize coating performance and cost all along their life cycle. A proof-of-concept for the most promising candidates is being developed and demonstrators will be produced and tested on fields.

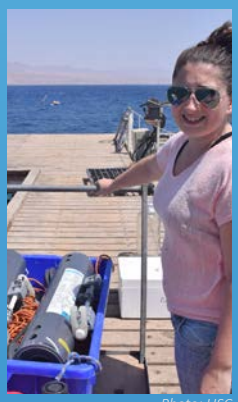

Photo: USC

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

Photo: Jotun

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

Description of work performed and main results

In **WP1** dealing with the project management tasks, the internal website (eRoom) for BYEFOULING partners with detailed information on the project was updated to promote an efficient project internal communication. The homepage for public access was regularly updated with open information. EB/MST meetings were conducted monthly. The 24M meeting was held on 25-26 November 2015 in Aveiro. The first periodic report was prepared and submitted to the Commission through the participant portal on 18 July 2015.

In **WP2** innovative antifouling approaches have been focused on studies on surface structuration and biomimetic surface composition, protein adsorption inhibitors, quorum sensing inhibitors and natural biocides and living active species were carried out. For surface structuration, new structured surfaces with wrinkles of 70 and 150 µm using mechanical and UV-ozone irradiation were obtained and plans for applying this technology to satellite buoys are currently undergoing.

Photo: USC

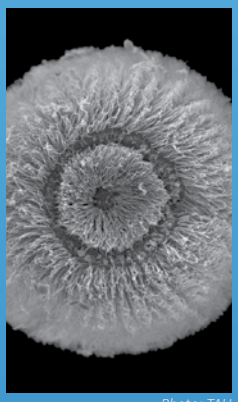
Photo: TAU


Photo: SMT

With respect to biomimetic surface composition the saponin content from the gut of H. scabra was characterized, the procedure for saponin extraction has been improved and proteome profiling of sea cucumber mucus has been initiated. In the case of protein adsorption inhibitors, two types of systems are being studied: peptide-like and poly-zwitterionic materials.

For peptoids large-scale production has been achieved adapting the method previously reported on M18, whereas for zwitterionic polymers the protocol of synthesis with a new CTA based on trithiocarbonate was optimized. In terms of quorum sensing inhibitors, three Bacillus strains with QSI activity have been identified, while anti-biofilm activity has been found in aqueous extracts from diatom and red alga. Concerning natural biocides, a new screening method based on TLC-agar was developed and antifouling activity has been found in several extracts of microalgae. Moreover, extraction with solvents was performed in attempt to isolate the components from microalgae biomass and the corresponding extracts tested against different fouling agents. Finally, in the field of Living Active Species, freeze-dried cells of different bacteria strains have been produced and have been used in the development of antifouling coatings.

In **WP3** related to the development of antifouling coatings were dedicated to synthesis and characterization of nanostructured inorganic, hybrid and polymeric materials that can be used as reservoirs for the encapsulation of active species have been undergoing. The synthesis procedures of different inorganic and polymeric materials loaded with biocides, reported in previous reports and with already proven activity, have been optimized and release of biocides characterized. Regarding living organisms, the encapsulation of bacteria spores with antifouling activity was carried out and spores demonstrated a higher resistance to be encapsulated into spheres according to the encapsulation conditions compared to bacteria cells. Concerning oligomeric silsesquioxanes, different methods for immobilization of antifouling compounds have been tried. With respect to functional fillers, nanoparticles were modified with quaternary ammonium salts and samples sent to partners for further characterization. Furthermore, polysaccharide-based formulations were developed and applied onto fishing nets and their activity is currently under validation, while waterborne formulations were improved with respect to previous attempts by increasing solid content and obtaining high conversions. Most of these materials have been already validated for antifouling activity and included in field tests.

In **WP4** dealing with antifouling performance and benchmarking (WP4), all the free compounds and intermediate systems developed were tested for anti-microfouling activity and anti-macrofouling activity against bryozoan, barnacles and mussels. Adhesion tests with coatings developed are currently being performed using barnacles and mussels. The toxicity of free compounds and intermediate systems on marine organisms is being investigated on different trophic levels. So far, 24 hour-acute tests on Artemia salina have been performed for all compounds, while acute toxicity tests on mussels, unicellular algae and sea urchin embryos are being carried out. The performance of the first systems developed within the project is being tested in the Mediterranean Sea following international guidelines. Ongoing field test experiments aiming at the optimization of coatings performance assessment for aquaculture applications are being carried out in the Atlantic Ocean, the Mediterranean and the Red Sea with commercially available material.

In **WP5** dealing with coating testing, methods for the assessment of the nanomechanical properties of coatings have been set up. In addition, several methods for the assessment of surface roughness in coated substrates have been developed.

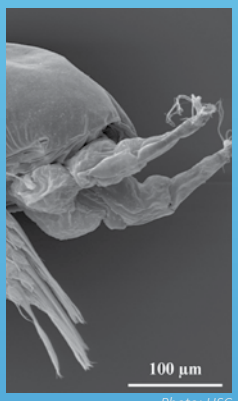

Photo: USC


Photo: USC


Photo: Jotun

Coatings have subsequently been exposed in the North Sea and the development of biofouling on these coatings, and more specifically the roughness that this induces, has being measured over the last 6 months. These results were made available to WP6 for modelling. Also, the investigation of fundamental aspects of biofouling and biocorrosion by marine macro- and microorganisms is currently undergoing. For testing of coating formulations, industrial partners have produced and applied coatings for field-testing with compounds and materials produced.

In **WP6,** activities related to the development of mathematical models for drag reduction prediction and activities related to LC Activities related to the development of the mathematical models for drag reduction prediction and activities related to LCA were continued. Experimental data was acquired to characterize the leaching of biocides from commercial paints in artificial ocean water under dynamic conditions and surface condition. Computational Fluid Dynamics has been used to simulate fluid flow and velocity profiles obtained for different surface roughness and the design of appropriate experimental rig for coating resistance has been completed and tests are already started. For LCA, a new model of paints has been created from an existing commercial paint and new antifouling solutions explored in the frame of this project modelled using available literature data.

In **WP7** activities on demonstrator design and exposure locations both for ships, aquaculture and for satellite buoys have been focused on the first design of a 3D-steel demonstrator with representative geometry has been proposed and first field tests at exposure locations both for ships, aquaculture and for satellite buoys have started. Moreover, one vessel actually in service was identified to be used in the frame of this project, namely to track hull performance. Upscaling activities of technologies defined as promising so far include active species, nanocontainers and fillers and are successfully proceeding to reach industrial scale.

In **WP8** several dissemination activities have been realised, including update of contents of external website (www.byefouling-eu.com), preparing several abstracts for conferences and scientific papers for submission in peer-reviewed journals. The BYEFOULING project was also represented at the Bioeconomy Summit held in Brussels on the 9-10 November 2015. Activities concerning exploitation have also been carried out.

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 because 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 when looking 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: TAU

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 life-cycle-costs will be significantly reduced, thereby increasing the efficiency and competitiveness of the ship transport industry. Furthermore, the project will 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, improved water quality and better control of disease vectors, reduce costs associated with copper waste disposal, enable lighter structures and improved resistance towards extreme weather and enhance the viability towards more stringent regulations on the use of biocides.


Photo: SMT

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.


Photo: TAU