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PROJECT FINAL REPORT

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Project acronym: FOUL-X-SPEL

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4.1 Final publishable summary report

Executive Summary

Marine Biofouling is a spontaneous and unwanted colonisation of micro and macroorganisms on surfaces in contact with seawater, either partially or totally submersed. In particular, it becomes one of the most concerns for the marine transportation business, as a result of serious economic an environmental penalties. For instance, its growth and accumulation on ships hulls' can be the main cause of efficiency decreasing, due to its effect on sailing speed and fuel consumption. Scientists and industrial ships companies have been reported the main specific and interrelated effects of this biofouling on ships hulls. One of the main effect, also responsible for other subsequent effects, is the hulls' surface roughness modification. It can lead to drag friction increasing up to 40% and subsequent power penalties of up to 86 % at cruising speed. To be aware of such huge effect of roughness on shipping, studies revealed that for an increasing on roughness of just 10 μm corresponds to a fuel consumption increase between 0.3 to 1.0 %. Therefore, and knowing that fuel consumption represents the biggest shipping operational cost contribution, which can goes up to 50%, the economic impact of this biofouling on marine transportation becomes a big headache for the business. Not being enough, an increase on fuel consumption also leads to a significant increase on greenhouse gas (SOx, NOx, CO_2) emissions. The International Maritime Organization (*International Maritime Organization, (2009) MEPC 59/INF.10*) estimated an increase of at least 50% of CO_2 emissions until 2030, under extreme scenarios.

On the other hand, this biofouling associated to the increasing traffic of marine transportation, also promotes the introduction of alien species in the different ecosystems, overpopulating and acting as predators to local species. Marine Biofouling constitutes indeed a major inconvenience for the shipping industry.

Protection hulls' strategies against such marine Biofouling have been extensively exploited for the marine industry. Nowadays, the most applied strategy to mitigate or control it follows biocide-releasing mechanisms, this is, coatings which emit biocides into the immediate surrounding area of the contaminated surface, thus killing and/or repelling potential fouling organisms before they can attach. However, the intrinsic ecotoxicity of those biocides and their continuous releasing has been leading to harmful side effects on aquatic ecosystems, becoming consequently less acceptable to the international community. Rigid regulations have been therefore issued (EU Regulation nº528/2012) which can compromise permission to use the currently available biocide based coatings. A demand on non-toxic technologies is sought. As a result a new non-releasing antifouling coatings generation is emerging. Most of the efforts done so far on the development of new potential antifouling coatings are still in an early stage of development and few were recent introduced in the marine coatings market. Among them, foul-releasing coatings (FRC) which act by physical mechanisms have been the most suitable to fulfil the non-toxic demand. Nonetheless, they still revealed some limitations, mainly associated to their antifouling efficacy only at non-static conditions (higher than 15 knots) and relative lower mechanical resistance, limiting their life-cycle to 5-10 years and posing higher maintenance costs. This project focused on a total new and innovative approach, which combine the advantage of the most efficient marine coatings technology with the chemical covalent immobilisation of commercial biocides. Thus offering potential new non-toxic coatings formulation with a wider range of antifouling action, especially with a higher resistance at harder conditions (static conditions), and subsequent improvements of shipping efficiency, and coatings life-cycle. In due time, the innovative coating(s) can be introduced in the market and become a rival on the marine coatings portfolio.

Project Context and Objectives

The marine biofouling (Figure 1) is one of most important factor that affects the efficiency of waterborne transportation since ships consume less fuel and thus less air emission of pollutants when their hulls are clean and smooth – free from marine fouling organisms, such as barnacles, algae or molluscs.

Figure 1. Biofouling on Ships´ Hulls, which lead to organisms deposition and biocorrosion effects.

With an estimated 300 million tonnes of bunker fuel oil consumed annually by the world's fleet there is an ever increasing focus on shipping's environmental footprint. The International Maritime Organization, IMO, (2009) estimates that without corrective action and the introduction of new technologies, air emissions, due to increased bunker fuel consumption by the world shipping fleet, could increase by between 38% and 72% by 2020. It is estimated that antifouling coatings provide the shipping industry with annual fuel savings of $60 billion and reduced emissions of 384 million tonnes and 3.6 million tonnes, respectively for carbon dioxide and sulphur dioxide per annum.

For this reason, the marine industry has been struggling to combat such biological attack and find an efficient method/technology to prevent it. The conventional method to minimise biofouling in modern times has been to apply coatings which emit biocides into the immediate surrounding area of the hull, thus killing potential fouling organisms before they can attach. It is becoming less acceptable to the international community to continue to leach biocides into the marine environment and recent history has seen the beginnings and further development of legislation. Several antifouling systems have been developed, but the most revolutionary generation was categorised by the appearance of the tributyltin (TBT) based paints, around the 1960s', due to its high antifouling efficacy and versatility. TBT Coatings led to significant operational savings, and ship owners found that for the first time, ships could stay clean and efficient for up to five years, which increased drydocking intervals and saved money. TBT, although a very effective antifouling biocide, is persistent in the environment and the ecotoxicity of TBT proved to be harmful to the marine ecosystem by interfering with a broad spectrum of marine organisms' lifecycles, and due to its slow degradation it started to accumulate in sediments in localised areas. As a result, TBT was globally banned in shipping by the International Maritime Organization (IMO) under the International Convention on the Control of Harmful Anti-fouling Systems on Ships (IMO AFS/CONF/26 - 18 October 2001). The final parts of this legislation came into force in September 2008. Since the ban, efforts have been made to fill the gap left by this biocide.

New tin-free antifouling coatings generation emerged, commonly characterised by the combination of toxic agents in paint formulations, usually complementing the potential biocidal action of a copper oxide with other booster biocides or co-biocides. These alternative coatings systems are recognised to be the most effective, but despite its effective antifouling action, the followed strategy evidenced serious drawbacks. These strategies follow a biocide-releasing mechanism, meaning a continued releasing of biocidal agents into the environmental, this accumulation, associated to their ecotoxicity, has been leading to harmful side effects on ecosystems. As a result, the use of such antifouling agents has been regulated internationally. The most wide ranging legislation is the EU Biocidal Product Directive (BPD) (Regulation (EU) No 528/2012 - 22 May 2012) which has already banned the sale of some named biocides for use in marine antifouling systems, and more restrictions are expected to come in a near future. Greener antifouling alternatives are sought in order to answering to this economic and environmental challenge in marine industry. Several non-biocidal technologies have emerged, but still evidence technical and/or environmental limitations (E.R. Silva, O. Ferreira, J. C.M. Bordado, Ho-Chun Fang, S. Downie, S.M. Olsen. *Marine coatings: A Systematic Study on structure-property relationship of potential covalently immobilized biocides*. Transport Research Arena 2014). For instance, and among the most recent developed paint technologies with commercial and industrial application potential, foul-releasing silicone or fluoro-silicone based topcoats seem to demonstrate promising improved hydrodynamic behaviour when compared with conventional coatings systems such as self-polishing coatings. Still those foul-releasing systems are limited to vessel speed, higher than 10 knots and 8 knots, respectively.

On the other hand, and in the point of view of vessel performance ship owners of oceangoing vessels spend considerable time and money to mitigate the effects of fouling on vessel performance. Typical costs of hull treatment during a drydocking can range from a few thousand dollars to a half million dollars depending on vessel size, the type of coating system applied, and the pre-treatment of the hull prior to the coating application. It is urgent to overcome the existent limitations found on protective and preventive anti-fouling technologies in order to promote sustainable shipping operations. New alternatives are sought.

Mission of FOUL-X-SPEL Project

The primary role of a ship antifouling coating is to limit the increase in frictional drag as a result of surface deterioration and biofouling accumulation. Frictional drag alone can account for as much as 90% of the total drag on some hull types, even when the hull is relatively smooth and unfouled. Hence, for a given ship design, the coating condition is crucial to the performance of ships. Frictional drag in a ship is directly linked to the interaction between the moving hull and the surrounding seawater. As the ship moves, a significant mass of water, sometimes reaching 1/4 or even 1/3 of the total mass of the ship, is accelerated to a speed close to that of the ship. The consequence of this is that the engine must deliver additional power to keep constant speed and thus greater fuel penalties. It is evident that to provide a long-term fouling deterrence is the most important feature when discussing the drag performance of an antifouling coating. This means that a future coating technology should combine the lowest possible initial friction with long term fouling protection until the next dry-docking operation (as much as 90 months later in recent cases).

The Mission of FOUL-X-SPEL Project is to provide an Environmental Friendly Antifouling Technology to Optimise the Energy Efficiency of Ships, aiming to overcome the above limitations, mainly regarding environmental harmful effects promoted by the releasing of toxic biocidal agents from conventional antifouling systems, limit range of antifouling action, as well as the subsequent retrofitting issues in shipping industry. It follows a total innovative approach for the development of a new antifouling paint. It combines the advantage of the most efficient marine coatings technology with the chemical covalent immobilisation of commercial biocides. Most of the proven anti-fouling and algaecides, if simply mixed into a paint, for instance in the top layer, will leach out within a short time, resulting in a complete loss of effectiveness. The innovative idea behind the current work plan of this project is to bind covalently those active ingredients to the back-bone of the main resin of the top layer of the coating system, thus offering a potential new non-toxic coating formulation. The new antifouling coating should have a lower friction against turbulent water than the reference coating to facilitate the hull-sea water interaction so that to optimize energy efficiency. It is well confirmed that none of the existing painting systems have used this approach, and if successful, the ultimate goal of this project, supported by the European FP7 Programme - THEME [SST.2011.1.1-1.][Green retrofitting through optimization of hull-propulsion interaction], is to offer an antifouling coating that avoids the leaching of toxic substances to the seawater, together with a long-term effect of surface protection (up to 90 months of exposure into seawater). The new surface coating technology will minimize the surface roughness and improve hydrodynamic properties of hulls, consequently minimize the effect of Green House Gas (GHG) emissions.

The new technology will be generated from research and innovative work provided by the collaboration of 10 international partners, which ultimate goal. The main expected results and also indicators of the project work plan progress can be summarised as:

- To select and carefully analyse the feasible to immobilise bioactive molecules in a polymeric matrix, in compliance with regulatory requirements and particularly under the European Biocidal Products Directive (BPD) for environmental concerns;
- To provide a coating with a low initial friction with water, maintaining the hulls' surface free of fouling;
- To provide prototypes and also the coating applied to surface of ships for sea exposure, using the developed paint and conventional antifouling coatings (for comparative studies);
- To reduce the immobilisation period, in dry docks, for hulls maintenance;
- Develop modular and cost-effective retrofitting technologies and environmental friendly processes for yards;
- Develop accurate assessment tools (mathematical models) for the determination of the environmental, energy and operational benefits, including energy saving of retrofitting solutions (hull-propulsion interaction) taking into account the remaining life cycle;
- Develop solutions and best-practice guidelines for efficient, safe and environmentally friendly retrofit processes, especially in which concerns surface protection.

In addition, the new type of coating is easily transferable for application in bridges and other inland metallic structures in coastal areas and wet zones. This project aims to demonstrate that is available use the non-dangerous biocides listed by European Union in order obtain a longer cycle of life with a superficial layer containing low concentration of biocide and not subject to leachate migrating for water. The environmental regulations must consider the advantages of this stable antifouling that will perform environmental advantages during the service, repaint and removal of coating waste of hull blasting and cleaning without possibilities of soils and water contamination before the final disposal.

To achieve such goals the FOUL-X-SPEL project is organised by twelve main work packages with several inter-linked activities. A detailed description of the main tasks and objectives in each work package can be found in the project website: **http://www.foulxspel-antifouling.com/**. Briefly, Managements activities of the project are planned and descripted in WP1. R&D tasks (WP2 to WP4) are planned to identify and select bioactive molecules, able to be immobilised in the coating matrix. Paint interactive formulation and assessment in terms of biocide immobilisation, activity, paint biodegradability, ecotoxicity and mechanical properties will be also included in WP4. From WP5 to WP10 lab and field tests (ships and developed prototypes) activities at different scenarios, to validate and certify the new antifouling coating are included. Comparative studies with reference paints will be also performed, which will constitute inputs for a benchmarking assessment, techno-economic validation and technical guidelines for Industry scale application (WP11). WP12 comprises dissemination and exploitation of the project results (workshops, conference participation, publications, forum of stakeholders, etc.).

Project main S&T results/foregrounds

The tasks planned have been performed by the Project Consortium since the beginning of the Project (December 2011 until November 2014). The main FOUL-X-SPEL achievements here described were subdivided based on the main performed activities, which can be found in the project website:

1. **Biocides binding (WP2 and WP3)**

This task involved activities which aimed to develop and test the viability of the novel biocide immobilisation strategy on polymeric paint components. In order to provide successful biocides immobilisations, a criteria's mapping of potential selected antifouling agents, which possess chemical structural points where the covalent binding has chance to succeed (Figure 1) was provided:

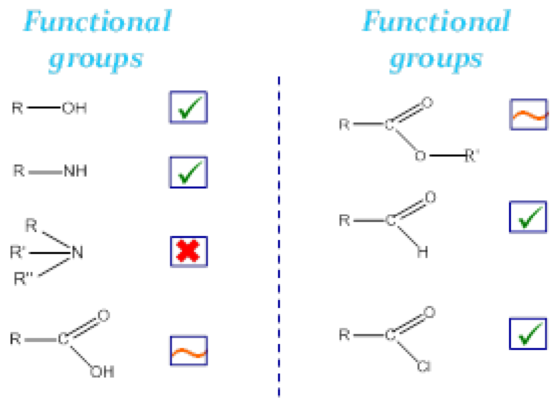


Figure 1. Example of biocides functional groups and their classification accordingly with their potential ability to be linked by covalently bonds.

In addition, classification of biocides accordingly with their mode of action (active by contact) was also included in this screening. A wide range of potential antifouling compounds where found as suitable for the marine antifouling purpose, but due the lack of information on their mechanism of action and feasibility for scale up and/or antifouling action under real conditions, the provided antifouling agents" list only considers the most promising agents for the covalent binding approach, based on the available data. These selected agents were further classified in accordance with: the existent regulations and/or restrictions, in order to better evidence their legal status of their use; their chemical stability and accessibility; and mechanism mode of action. The resulted classification of representative potential biocides is here illustrated by coloured cells in Table 1 and 2. Details of this classification criterion can be found the on-line published paper: E.R. Silva, O. Ferreira, J. C.M. Bordado, Ho-Chun Fang, S. Downie, S.M. Olsen. *Marine coatings: A Systematic Study on structure-property relationship of potential covalently immobilized biocides*. Transport Research Arena 2014.

Table 1. Antifouling agent's selection colour classification for the predefined criteria

Colour	For the criteria: Mechanism of action, Potency, Stability and Accessibility	EU Biocidal Products Directives (BPD)
Red	Not feasible	Not allowed in EU based on BPD
Yellow	Not feasible for some criteria	Existing antifouling agents under review in BPD
Green	Potential antifouling agent	New biocide under evaluation in BPD
Blue	May be feasible	----------
	Lack of information to be taken any decision	----------

Table 2. Antifouling agent's selection based on the predefined criteria

Antifouling agent	Mechanism of action	Potency	Stability	Accessibility	Original material to be registered in BPD
Irgarol	Red	Green	Green	Green	Yellow
Polyethylenimine	Green		Green	Green	Red
Quaternary Ammonium Salts	Green		Green		Red
Momilactone A or B			Red		Red
Kalihidol A			Red		Red
Isocyanosesquiterpene alcohol /furanosesquiterpene			Red		Red
Medetomidine	Green	Yellow		Green	Green
Econea	Blue	Green	Red	Green	Green
Mancozeb	Blue		Red		Red
Zineb	Blue	Green	Red	Green	Yellow
Capsaicin	Red	Yellow	Yellow	Green	Red
Capsaicin analogues	Red	Yellow	Yellow		Red
Galactosamine	Green				Red

In this project two main potential biocides, Econea and Irgarol, have been successful immobilised following strategies that can include a prior derivatisation step or other strategy. Partners involved filled a patent application on the scope of derivatise biocides for further immobilisation in paint formulations (*E.R. Silva, O. Ferreira, J. C. Bordado*. PT Application nº 108096, 12 December 2014).

Binding studies, performed between the biocides and conventional and non-conventional resins, followed by their assessment regarding binding efficiency and residual activity after binding were performed to validate the immobilisation effectiveness.

Nonetheless, and depending on the technical requirements for the immobilisation of biocides or bioactive agents in the paint components, adjustments or even alternative strategies revealed to be needed along with the project progress, in order to guarantee the basic properties required for an antifouling marine paint, including non-leaching products and validation of its antifouling effect.

These adjustments/activities were performed on the corresponding WPs activities plan, related to the paint formulation, mainly WP4/WP6.

The main obtained results from the performed activities in this task can be summarised as:

- Modified or derivatised biocides have been proven reactive with non-conventional and conventional resins;
- The followed strategies to provide covalent ability to biocides for polymeric matrices, didn't penalise the biocides bioactivity;
- Compatibility studied of the biocides with polyurethane and silicone based systems, evidenced good results, but polymeric systems optimisation is always required in order to balance the basic marine paint properties with the additional introduction of additives, in particular the biocides;
- From algae tests according with OECD 201 neat Econea and Irgarol are toxic but the samples of derivatised Econea revealed non-toxic behaviour against algae.
- From Daphnia tests according with OECD 202 all samples (neat Econea and Irgarol as well as derivatised Econea and Irgarol) behaved toxic.
- Vibrio Fischeri tests were performed at two different pH, acidic one (due to the nature of the biocides tested) and neutralized one (more realistic taken into account the real application in seawater). All Econea samples showed bacteria inhibition at both pH but Irgarol samples (neat and derivatised) did no showed inhibition in this case.
- Vibrio Fischeri tests were repeated on latest synthesized biocide derivatised samples developed by IST by using Flask method in order to get a better accuracy in toxicity results, due to the control of solubility. Again derivatised Econea samples revealed inhibition and slight toxic behaviour (in the worst case, $EC50>300mg/l$).
- Biodegradability studies (OECD 301F tests) were also performed for these first functionalised biocides. The results evidenced that the biodegradability of the developed derivatised biocides is substantial higher than the commercial Irgarol and Econea.

Potential results were obtained for the modified commercial biocides and their linkage on conventional and non-conventional base systems. This is an extremely important step which allowed for further immobilisation and optimisation of biocides in marine paint systems, activities comprised in next paint formulation task (WP4 and WP6). In addition, further needed adjustments on paint formulations, regarding industrial required technical properties for marine environmental, including environmental compatibility assessment (biodegradability, toxicity) of paint formulations, were included in paint evaluation task.

2. Paint Formulation (WP4, WP6)

Development of non-biocide releasing paint formulation has been the main goal of this task, with potential to be incorporated into the busyness of a modern industrial coatings supplier, such as the project partner HEMPEL. Initial results revealed that the efficacy of the immobilised biocides in polyurethane and silicone coatings in relatively low amounts provided insufficient antifouling performance against biofouling. In order to increase the potency of the biocide, different solutions were pursuit. Combining different biocides, increasing biocide load, and adding zwitterions for improved physical effect.

Polyurethane based coatings

Studies revealed that a combinatorial effect does improve the antifouling performance of polyurethane based coating. The observations of the exposed prototypes revealed potential results. At week four of the immersion test no significant biofouling was observed in the samples containing a combined. Similar behaviour was found after 3.5 months of sea immersion, revealing the formation of a very weak adhered biofilm. The FOU-X-SPEL polyurethane-based coatings were therefore based on the combinations of different immobilised biocides (Econea and Irgarol), and further prototypes static tests were performed to continuing assess the antifouling behaviour of polyurethane based formulation for longer period.

PU systems are recommended to a maximum total biocide content of 10 wt. %, and it is preferable to use lower contents in order to avoid the loss of other paint properties, but such choice will depend on the balance between biocidal efficacy and paint properties, which should be tailored in accordance with the sweater conditions and biota.

Silicone based coatings

Silicone-based formulations pose a particular challenge when formulating with new ingredients. Technical limitations, mainly associated to the incompatibility of new ingredients, highly limit the inclusion of higher biocides content or even mixtures of biocides.

Nonetheless, the work developed allowed providing the best practice of incorporating resin-based biocides into silicone antifouling paint systems. Thus, and in order to obtain a homogeneous coating upon application, drying, and curing, the ingredients must be compatible with polysiloxanes. Only some siloxane-based compounds can be incorporated into a silicone coating, without added measures. The defined precautions will allow for a homogenous film of a silicone coating containing immobilisable Econea.

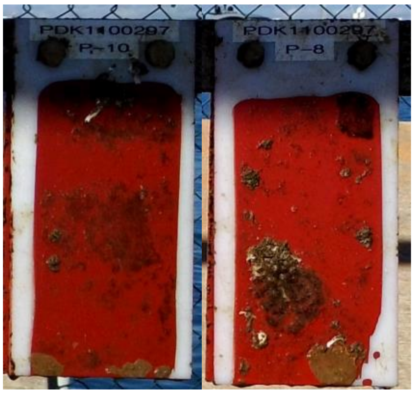


Figure 2. Phosphorylcholine-based zwitterion in a silicone-coating (left), and zwitterion-free reference (right). Immersion in Spain.

Because of the low amounts of biocide allowed (< 1wt. %) in the silicone based coating, means to increase the non-fouling properties of the coating system was investigated. Synergistic studies were and are being conducted for silicone based formulation, by the immobilisation of combined derivatised biocides. First results show that the biocides combination seems to favour the increase of the total biocide content, and the first antifouling performances for 21 weeks sea immersion tests were very promising, no relevant biofouling was verified.

In addition, it was also proved that zwitterions did improve the non-fouling properties of silicone-coatings against especially animal fouling. Hempel has filed a patent application covering this invention (*S. M. Olsen, P. C. W. Thorlaksen, D. M. Yebra*. Polysiloxane-based fouling-release coatings. Application WO 2014177159 A1, 2014). An example of the paint formulation performance with zwitterionic immobilisation is shown in the following figure 2.

The above main paint formulation activities, were also supported by other related activities in order to tailoring the paint formulations and accomplished the properties required as an antifouling marine paint. Activities such as prototypes antifouling performance assessment in seawater immersion tests at different places, physical and mechanical performance, leaching tests and toxicological analysis were the main complementary activities.

From toxicological analysis, in particular leaching waters analysis, obtained from the developed formulation containing the immobilised biocides, didn't evidenced toxicity for the Luminescent bacteria Vibrio Fisheri. These results are promising, but other environmental impacts should be addressed regarding paint formulations, this was performed in the frame of Modeling of energy and environmental efficiency task.

All the above achieved results allowed the Consortium on the final paint formulations decision. Two main formulations were selected, one polyurethane based paint containing two immobilised derivatised biocides (Econea and Irgarol), and a silicone based formulation containing immobilised Econea. These formulations are currently being assessed on real conditions. Details of these tests are further described as part of the field trial tests task (WP10).

3. Paints evaluation (WP5, WP7, WP9)

The above mentioned novel antifouling paints developed in FOUL-X-SPEL project were fully characterised, mainly in terms of their basic properties, environmental compatibility, salt spray tests, UV tests, electrochemical and mechanical resistance, drag friction reduction, antifouling performance on developed prototypes, which involved several partners' expertise and know-how. It is here described the main evaluated properties of the developed paints and the results achieved.

<u>Basic properties of the paints</u>

The different developed paints formulations with and without different amounts of biocides have been use to prepare coated panels prototypes, which were submitted to different characterization tests in order to compare the basic properties of the new developed coatings and compare their response with reference paints already available in the market. The following tests were performed on the project paints: abrasion resistance, wettability, thickness, washability, scratch resistance and hardness. At the end the different formulations tested were screened and compared in order to select the most suitable ones for further characterization.

Modelling activities were also accomplished by using CFD (Computational Fluid Dynamics) tool. Different CFD approaches to the roughness effect on flow, turbulent boundary layer and frictional resistance were investigated and the most suitable CFD modelling techniques such as turbulence and roughness function models were determined by carrying out several parametric studies. Since, the focus was on the flow around ships, multiphase flows and the resistance prediction of ships were considered and some basic models were determined which were convenient to the nature of the phenomenon. After the investigation of the resistance prediction of smooth surfaces, the roughness effect on resistance was also investigated. An extensive research was conducted and a complementary in-house tool was developed to obtain the required quantities to be employed in the software.

During the project duration, several environmental analysis involving toxicity and biodegradability tests were accomplished on different samples. At the first stage of the project, pure biocides were analysed as potential candidates to be involved in final paints formulation. Additionally, further toxicity tests on leaching products were performed in order to evaluate the toxicity of the paint release. Concerning eco toxicity assessment, three basic level tests proposed and included in the EU hazard assessment of substances and European Eco-label have been performed. Daphnia acute immobilization test (OECD 202), Luminescent Fibrio Fischeri bacteria test (ISO 11348-2), and Alga growth inhibition test (OECD 201). According with EU requirements the 50% effect level is chosen, the level at which 50% of the test organisms show an adverse (lethal) effect. Biodegradability tests were also studied according with OECD 301F. Toxicity and biodegradability results obtained all along the project duration were detailed reported in different deliverables.

In order to evaluate experimentally the drag friction coefficient of the project paints formulation a new test rig was designed and manufactured (Patent P140368EP). The estimation of the drag friction coefficient allows correlating the surfaces modification due to fouling with the energy and fuel consumption due to the increase of the surface's roughness. According to this, different experimental tests were performed on coated test samples and different formulations were compared in terms of their frictional response in artificial seawater, as well as after being subjected to field tests, either in static or non-static (attached to ships – on field tests task) conditions.

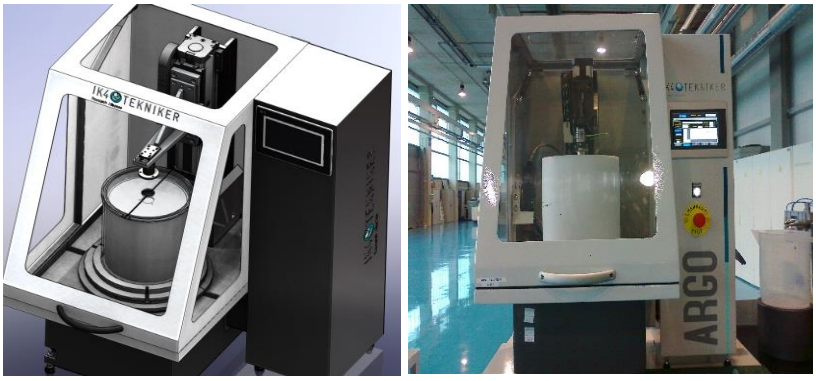


Figure 3. Different images of the drag friction test rig. (IK4-Tekniker)

In relation to legal issues related to the use of biocide molecules, a thorough review of international legislation and regulations was carried out during the project, with special focus on the current European Biocidal Products Directive (BPD) and the upcoming new EU No 528/2012 Regulation which will enter into force on 1 September 2013. Other legislations and their national committee work, such as those from the Scandinavian countries, the USA, and New Zealand, were monitored regularly.

The regulatory experts in FOUL-X-SPEL project contributed to the implementation of the BPD and its potential effect on the new developments. Contact was made with the UK Health and Safety Executive (HSE) and Direcção Geral da Saúde (General Directorate of Health) to discuss their interpretation of BPD and the approval procedures by the regulatory bodies. The UK HSE had commented that the special production methods the FOUL-X-SPEL team adopted (biocide bonded to another molecule could be classed as new (biocide) molecule) would be assessed on a case by case basis. This was especially important considering the potential requirements in applying the Experimental Use Permit (EUP) in different tasks of the project and addressing the marketability of the future FOUL-X-SPEL products within the EU. Regular review on the update of the development in international legislations was performed during the project to ensure that the technology development follows relevant requirements from the governments and international bodies.

Other characterisation techniques have been used to fully assess the developed paint formulations. These tests included, among others, salt spray tests, UV tests, electrochemical and mechanical testing.

- Salt spray tests were performed on antifouling coated specimens on both intact and scribed conditions. In intact state, the silicone-based paints seemed to retain their electrochemical, optical and mechanical characteristics unaffected. The new silicone developed formulation within the FOUL-X-SPEL project presented the best performance in intact state, while the polyurethane developed formulation in the scribed state.

- UV tests were performed on the same coatings in intact state. The rest of the specimens of all the systems remained unaffected, exhibiting a purely capacitive behaviour, with the exception of the acrylic commercial reference coat used (SPC) which exhibited some degradation at the end of the test. Pendulum hardness increased for the acrylic and polyurethane coatings, but remained the same for the silicone systems. Visual observation showed some gloss variation among the systems and intense discoloration and checking effect on the surface of the acrylic based paint. No chemical degradation was detected for all the paint systems examined. The silicone paints exhibited the best behaviour during this test, followed by the polyurethanes and finally the acrylic paint.

- Laboratory immersion tests in 3.5% NaCl solution were performed on antifouling coatings in intact state. Six (6) months were completed for the commercial and three (3) months for the project developed (a polyurethane antifouling and a silicone antifouling) paints. The silicone reference paint remained electrochemically unaffected, while the acrylic reference paint exhibited some degradation after the third month of immersion, which was also chemically detected through the FTIR measurements. The newly developed paints remained electrochemically unaffected after three months of experiment. Finally, the pendulum results revealed that the developed silicone paint retained its hardness, while the polyurethane appeared to become harder with time. In general, the project developed silicone antifouling exhibited better performance than its polyurethane counterpart.

- EIS measurements revealed a purely capacitive behaviour for almost all the coatings examined under accelerated and natural ageing tests and a very low percent of water infiltration for almost all the coatings (below 0.5%). Only the acrylic painted specimens exhibited some degradation during the laboratory immersion test. These observations lead us to suggest two types of equivalent circuits, namely the former for the purely capacitive behavior consisting of the solution resistance in series to the capacitor and the latter for the coatings exhibiting an R_{pore} value, consisting of an extra R_{pore} resistance element in parallel to the capacitor. In addition, all the systems were examined with the liquid-water transmission rate test and presented *low rate* of water permeation. Finally, the same coatings were evaluated under the effect of household chemicals, where the acrylic coat was mostly affected.

- A variety of mechanical tests were performed on the reference paints (silicone and acrylic) and on the newly developed (silicone antifouling, polyurethane antifouling) paints. Tests such as, König pendulum hardness, pull-off, tribocorrosion and toxicity tests were performed. From all the performed methods the project developed polyurethane antifouling exhibited the more satisfactory behaviour followed by the silicone formulation.

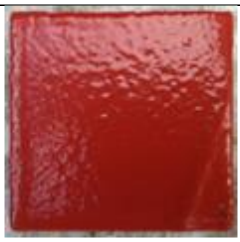
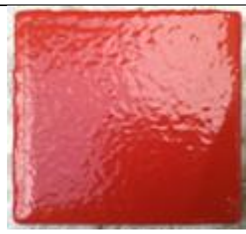
<u>Paint application/Painted prototype panels</u>

In order to apply the developed new paint as retrofitting technology to the hull of existing and new ships, the performance of the new paint should be tested in terms of drag reduction and fouling performance that will improve the energy efficiency of existing ships. Of course, improved energy

efficiency through drag reduction will also result in the reduction of Green House Gas emissions as well.
Specific objectives achieved within this task were:
- The design and construction of prototypes systems for laboratory and field sea exposure tests;
- To perform resistance tests of the developed prototypes for both conventional and new developed antifouling paints;
These activities allowed providing real data on paint performance in terms of energy efficiency.

a) *Prototypes for laboratory testing (on steel panels)*

Design and construction of steel panel probes for laboratory tests were conducted by the partners to evaluate the application of new antifouling paint, namely concerning the level of surface preparation in order to assure an optimal adhesion of coating. The tests conducted used different samples of seawater collected locally in the harbours located in river and sea coastal areas. The tests were made in accordance with the more exigent standards and class society's rules.
The panel probes for laboratory tests were designed and constructed following the requirements defined by each of the partners involved to evaluate the application of new antifouling paint, namely concerning the level of surface preparation in order to assure an optimal adhesion of coating. The final appearances of the panels coated with reference samples are given below together with the brief descriptions.

FOUL-X-SPEL reference 1 Silicone base	**FOUL-X- SPEL reference 2** SPC (acrylic based)
	
Main features: Shiny surface; Smooth surface and tactfully like plastic (silicone)	Main features: Matt surface, Surface with some roughness and possibly with some powder

b) *Prototype for sea exposure testing*

Experimental paint formulations that were been previously selected have been immersed for sea exposure tests in Gulf of Elefsis (Greece), Spain-Mediterranean sea, Singapore – Indian ocean, Peniche – Atlantic sea (Portugal) and Southampton (England). A finalised silicone-based paint has been immersed in seawater in Greece, Peniche-Portugal and in the UK for more than 45 days and will continue beyond the project. A polyurethane-based paint has been in the sea for 14 weeks in Peniche and test has been promising. These preliminary tests helped us to select the best polyurethane based formulation developed so far for field trial tests. Nonetheless, and since the results from the tests depend on the particular local seawater conditions and biota, new prototypes have been prepared with some of the best formulations and with new ones, including silicone based formulations and controls prepared by following a same procedure and the same commercial resin, in order to look for better antifouling behaviours, as well as to expose the prototypes in other seawaters conditions (e.g. Portuguese coast and Singapore). It should be also mentioned that the immersion tests were performed in static conditions, and therefore the unattached slime is expected to be removed on non-stationary applications, such as on hull of ships. The results were promising for the both polyurethane and silicone based formulations for instance after 24 weeks immersed in Singapore or 21 weeks at NOC raft Southampton.

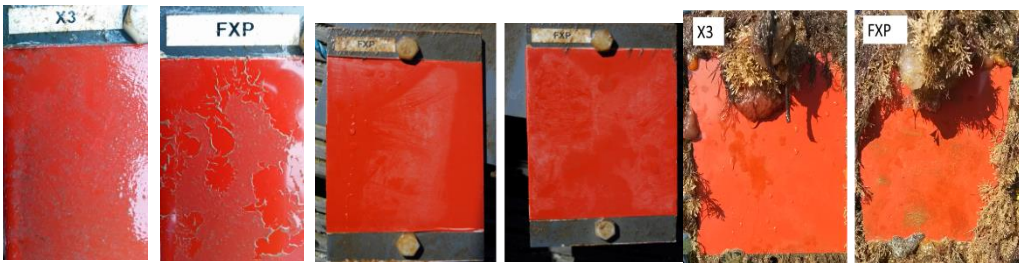


Figure 4. Coated prototypes after 4, 8 and 21 weeks (6 months + 1 week) of seawater exposure at the NOC raft, Southampton, UK. Coatings: Reference silicone based coating X3 and new silicone FOUL-X-SPEL (FXP) coating without leaching.

c) *Prototype resistance tests at lab scale in hydrodynamic basin*

The ultimate aim of this task is to determine the performance of the new FOUL-X-SPEL paints in terms of drag reduction and energy efficiency for existing hull surfaces. An extensive series of towing tests of the flat plates coated with different antifouling coatings were carried out at the Kelvin Hydrodynamics Laboratory (KHL) of the University of Strathclyde. The surface roughness amplitude parameters of all the test surfaces were then measured using a hull roughness analyser.
6 different surface conditions are considered in the experiments given below:

- Reference Plate (sanded and polished)
- FOUL-X-SPEL reference 2 paint (SPC) – FXP-R2
- The new FOUL-X-SPEL Polyurethane system with immobilised biocide (s) – FXP-N2
- The new FOUL-X-SPEL Silicone system with immobilised biocide – FXP- N1
- FOUL-X-SPEL reference 1 paint (Silicone) – FXP- R1
- Grit-blasted surface (Hull)

In total over 150 runs were carried out, including a series of repeat tests designed to quantify the uncertainty in the results. The drag coefficients of each surface were obtained and presented in a comparative manner along with the uncertainty limits of the experiments.
In conclusion, new FOUL-X-SPEL Paint (silicone system with non-leaching fixed biocide) showed the best as-applied drag performance among all of the antifouling coatings.

Figure 5. FXP-R2 is being towed at a low speed.

Table 3. Antifouling paints rankings and the change in total resistance coefficient with respect to Reference Plate and Hull.

Antifouling Paint	%ΔC_T (WRT Reference Plate)	%ΔC_T (WRT Hull)
FXP-N1	-0.74	-3.14
FXP-R1	0.175	-2.25
FXP-N2	0.9	-1.539
FXP-R2	4.82	2.275

4. Modeling of energy and environmental efficiency (WP8)

The objectives achieved within this task were:

- Modelling of the roughness effects of antifouling coatings and biofouling on ship performance
- Determination of the time dependent hull roughness of the new paint and its effect on the energy efficiency performance of existing ships retrofitted with new paint
- Development of a semi-empirical formula to predict the time dependent drag performance of different antifouling coatings
- Development of a model to determine the energy and environmental efficiency of the new paint within Energy Efficiency Design Index and Energy Efficiency Operational Index of existing ships.
- Performing comparative Life cycle cost analysis for existing ships retrofitted with new coating against existing coatings
- Investigation and determination of the environmental impact of the new paint as a new retrofitting technology within through Life cycle framework
- Development and performing risk assessment of hull fouling on accidental release of the non-native marine organisms

The main achieved results were:

a) Regarding the effect of coating roughness on ship performance, an in-house prediction code has been developed to predict the frictional resistance of ships exposed to fouling or any type roughness based on Granville's similarity law scaling procedure. An extensive database of ΔC_F was evaluated for a range of fouling levels over time, ship lengths and ship speeds. Finally, a semi-empirical formula is developed using the generated database by means of regression. A case study was performed to predict the DCF values of the fishing vessel of ENP (M/V "INFANTE D. HENRIQUE") for 180 and 500 days of immersion for Spain. The predicted values for 180 days and 500 days are $\Delta C_{F(180)}$ = 5.98E-05, $\Delta C_{F(500)}$ = 1.042767E-03 respectively. The photographic evidences of the hull surface condition from the inspection report after 6 months, supports the expected insignificant fouling and hence insignificant increase in the coefficient.

Figure 6. M/V "INFANTE D. HENRIQUE"

The main advantage of the proposed formula is that it enables the use of immersion time directly for the aforementioned regions rather than using roughness heights or fouling levels. By using the formula, one can easily estimate the added resistance, hence fuel penalty of a ship over time.

Therefore, it becomes very practical to calculate the benefit of a new antifouling coating directly after some immersion time.

b) A mathematical modelling of the energy and environmental efficiency due to the time dependent performance of antifouling paints was achieved by using the EEDI and EEOI concepts.
A simplified dynamic ship model that captures the effect of hull roughness, namely antifouling coatings' roughness in the context of EEDI and fouling in the context of EEOI has been presented. A factor which includes the increase in the resistance coefficient due to hull roughness has been proposed. The effect of initial surface roughness and fouling has been employed in the EEDI and EEOI equations as the aforementioned factor. By this way, new predictive EEDI and EEOI formulae have been proposed.
Additionally, characterisation of the fouling component from real ship operational data has been demonstrated. A case study has then been carried out in order to predict the EEOI of a tanker using the proposed model.

Table 4. Design parameters of the ship in question.

Description	Symbol	Value	Units
Ship Class		TANKER	
Length (overall)	**LOA**	270	M
Breadth	**B**	46	M
Depth	**D**	24.5	M
Draft	**T**	16.2	M
Deadweight	**DWT**	150000	T

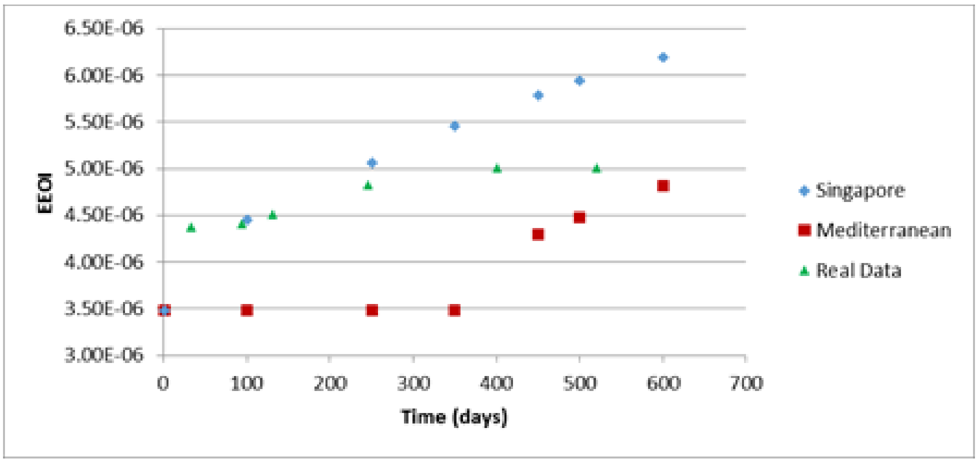


Figure 7. Predicted EEOI values together with the real EEOI values of the ship.

The main advantage of the proposed model is that it can be used for every type of coating and fouling conditions. That is to say, once a new paint is developed, the model can easily be applied to predict the energy and environmental efficiency of the paint once its time-dependent drag performance is known.

c) A methodology and a model were developed for Life Cycle Assessment (LCA) of antifouling paints with regards to fouling and maintenance of ships. The methodology is based on mathematical models of fouling growth vis-à-vis the impact of the environmental factors involved in coating and hull maintenance together with the environmental cost of emissions due to fouling. The FOUL-X-SPEL consortium has conducted numerical and experimental studies in the previous work-packages and the LCA methodology arise from the results of those studies as well as additional data provided by the partners of the consortium. Comparative analysis was carried out to show the ship operators' actual benefits/costs of using the new coating by using University of Strathclyde's Life Cycle Assessment Software. This software takes into account all the parameters related to fouling, maintenance and repair.

Following the introduction of the new LCA model, a case study was carried out to show how to use the model using a tanker which is assumed to be coated with 2 different types of existing reference coatings, namely a fouling-release coating (FXP-R1) and a tin free self-polishing antifouling paint (FXP-R2). The total costs and emissions due to the use of different antifouling types are calculated for the whole life-cycle of the ship. The results suggest a saving of 2.5 % due to the use of FXP-R1 with respect to the use of FXP-R2.

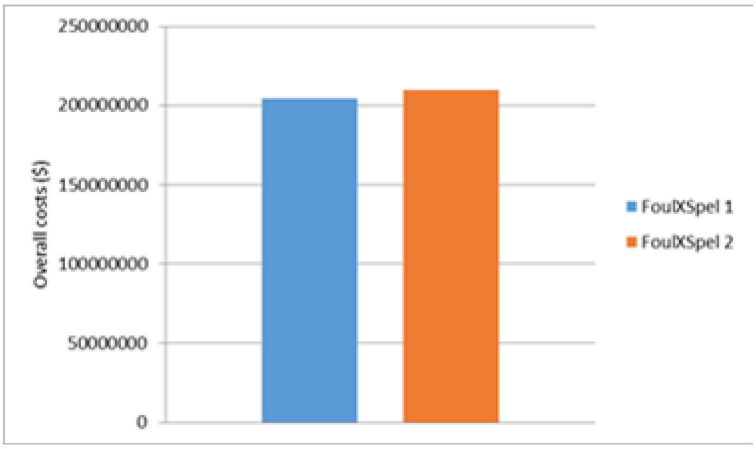


Figure 8. Overall costs over 30 years. FoulXSpel 1 = FXP-R1 and FoulXSpel 2 = FXP-R2.

The developed LCA model can help stake-holders determine the most feasible paint selection as well as the optimal hull-propeller maintenance schedules and make condition based maintenance decisions. It has been found that CO_2 emission reduction due to prevention and eradication of fouling can be achieved while reducing the cost – meaning that it is profitable (by way of fuel cost reductions) for the ship-owners to reduce emissions through fouling prevention despite the additional capital expenses.

d) Risk assessment of hull fouling as a vector for marine non-natives: Hull fouling is a significant vector for the introduction of non-native species due the loss of antifouling coating action. The type of antifouling coating (toxic versus non-toxic) is the most important influence on macroalgal fouling assemblages. The risk of accidental release of non-native marine organisms directly into the sea is therefore multiplied, particularly in harbours or transport hubs where maintenance operations occur. This task assumes to study the action of new coating achieved in project research in order to eliminate the risks of maintenance operations, especially during the dry docking and hull cleaning works and repainting in ships in the harbours/piers. The test panels submerged in the sea and rivers can deliver relevant information comparing the project antifouling with other paints available in the market.
Task partners participated in photographically recording the fouling communities, and where possible at each site identity and catalogue the local ecology in order to assess the potential risk of the selected AF paints. Temporal and geographical population dynamic could then be assessed along with species composition and diversity.
The field tests were conducted in Elefsis Gulf, according to the ASTM D-3623 standard for shallow submergence. Twelve (12) specimens per reference paints were submerged in the site. So far, eight

(8) months have been completed. Additionally, the two reference paints (FXS-R1 and FXS-R2) were applied by Hempel on plastic substrates (as opposed to the metallic ones) and immersed at Elefsis.

5. Paint performance validation at industrial scale (WP10)

The objective of this task is to determine the anti-fouling performance of the coated specimens immersed in real-time seawater conditions. Various panel exposure tests were conducted at different locations (e.g. Elefsis in Greece, Singapore, Spain, Portugal) during different seasons. Two sister long liners were identified to support the full scale ship trials. Panel exposure tests, probe tests, full scale ship trial and inspection of control products, benchmarking survey, and a simulation of fouling on ship hydrodynamic resistance were conducted under this task. Data collected under the ship trial were forwarded, to the previous task to Model verification in terms of energy and environmental efficiency.

From panel exposure (static conditions) test probe assessment inspection the main results and observations were:

- In all cases, the used polyurethane reference (negative control) exhibited heavy fouling, since it is not an antifouling paint and serves mostly as a negative control for the PU formulations.
- The acrylic reference paint (FXP-R2) exhibited mostly slime, which in some cases (e.g. after 6 and 8 months of immersion in Elefsis) formed a homogenous layer on the surface. No macrofoulers were found attached.
- The silicone reference (FXP-R1) presented some tubeworms already after 4 months in Elefsis, as well as, in Singapore and Spain tests, whereas in Portugal only show some slime (after 6 months). In Elefsis, the problem seemed to be more intense, especially after 12 months of immersion, where very long *serpulids* were found onto the specimen surface. However, despite the fact that this reference paint seems to allow macrofouling growth on its surface, the foulers are easily detached from the surface with gentle finger pressure. This verifies the low surface tension of the surface, which does not allow the organisms to easily attach, settle and grow on such a slippery surface.
- The new silicone FXP-N1 paint seemed to remain clean, in general, after most of the field tests. In Elefsis, some macro-foulers appeared already after 2 months of immersion, but this could be attributed to the time of immersion of the metallic specimens (July). At this summer time of the year, the activity of the organisms reaches its peak, so this could negatively affect the paint. From the tests in Portugal (Atlantic sea), this paint exhibited some silt after 21 weeks (nearly 6 months).
- The new polyurethane based paint FXP-N2 exhibited some long tubeworms on its surface, gathered in a small part of it, after 24 weeks (about 6 months and 2 weeks) in Singapore.

Please note that panel immersion tests of different products had been conducted across different seasons. Differences in biota are expected, and therefore on the antifouling performance, which can be adjusted by biocides content changes.

Adhesion loss, hardness change, and surface roughness of those exposed panels were evaluated .A panel exposure standard was created under this task to establish a common practice to evaluate the degree of biofouling and physical performance for project FOUL-X-SPEL.

Full-scale ship trial

ENP introduced two sister long liners to FOUL-X-SPEL to support project FOUL-X-SPEL's full scale ship trials. The new developed coatings formulations were prepared by Hempel. Hempel experts were travelling to ENP to supervise the full-scale paint application and inspection. In parallel, LRS hydrodynamic/machinery/coating experts and ENP were supporting from paint application, equipment installation, to ship trials. The vessels; service speed is around 10/11 knots. An annual maintenance is usually conducted during summer, in which was scheduled for the FOUL-X-SPEL paint application.

On the following figures show ENP ship with the newly developed formulations launched in 2014, an on-board view and a representative photo of underwater inspection. In addition, there was also launched a sea trial supported by SU's research yacht. These field tests will continue to be monitoring to assess the antifouling performance of these products even after FOUL-X-SPEL ending, with the support of (IST, HEMPEL, ENP and SU partners).

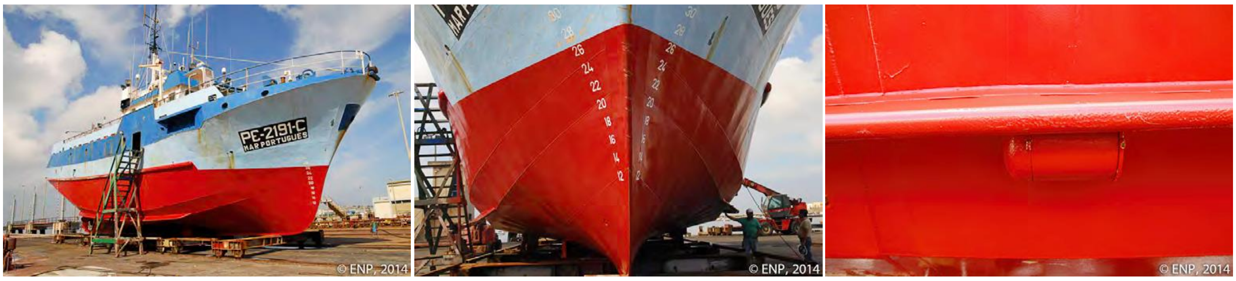


Figure 9. Vessel "Mar Português" painted with a new FOUL-X-SPEL silicone based non-leaching coating (FXP-N1). Field trial test launched in September 2014. A drag friction prototype was fixed to the vessel (right).

Figure 10. Vessel "Infante Dom Henrique" painted with a strip of new FOUL-X-SPEL polyurethane based non-leaching coating (FXP-N2). Field trial test launched in October 2014.

Figure 11. On-board view during a trial conducted in Aug 2013 (left); a snapshot of the colour video taken from the underwater inspection of Mar Portuguese in May 2014 (9 months after the (silicone reference FXP-R1) paint application.

Three dimensional model of the long liner was imported into the general purpose CFD code STAR-CCM+ by LRS. A comparison of CFD results between three trials were conducted accordingly.

Experimental Investigation of the Effect of Fouling on Ship Hydrodynamic Resistance

Following the full scale sea trials of the paints applied on the ships as well as studying a number of drydock reports with regards to biofouling, biofouling trends in terms of surface area and type of biofouling in various seas were established. In order to study the effect of biofouling on hull resistance and hence the fuel consumption, an extensive series of towing tests of the flat plates covered with artificial barnacles were designed and carried out at the Kelvin Hydrodynamics Laboratory (KHL) of the University of Strathclyde. The tests were designed to examine the effects of two different fouling parameters, namely the coverage percentage and locations of the accumulation. Therefore, 7 different configurations were prepared using 3D printed artificial barnacles. One of the configurations is shown in the following figure.

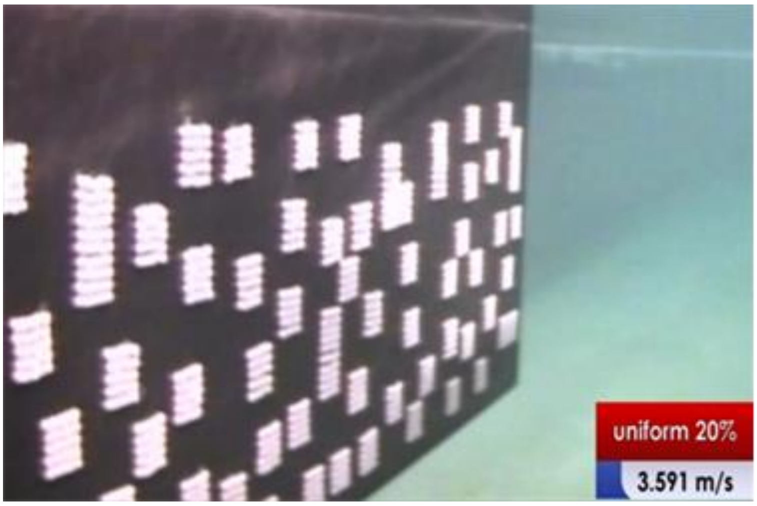


Figure 12. Snapshot from the underwater videos of Plate 3.

A novel approach was developed by modelling the fouling using the artificial barnacles, which were 3D printed and glued on the surface of the plates. This technique which is used first time in the world, provides a unique opportunity to determine the different fouling rates and locations on the hydrodynamic resistance of plates systematically. This also eliminates the problems and uncertainties, which are encountered during the transportation of the plates from sea to the tank including transfer of the marine life from seawater to freshwater.

The use of artificial barnacles allowed us to be able to carry out a well-defined parametric study. It is of note that these parameters were chosen based on the observations on real ship hulls. It is a well-known fact that the effect of the existence of other fouling organisms becomes negligible when the hull is covered with barnacles. Thereby, barnacles are chosen to be the working organism in these experiments. The experiments are therefore, expected to reflect the effects of real hull fouling on ship resistance.

In total over 130 runs were carried out, including a series of repeat tests designed to quantify the uncertainty in the results. The drag coefficients of each surface were obtained and presented in a comparative manner along with the uncertainty limits of the experiments.

Some of the results are given in the figure below.

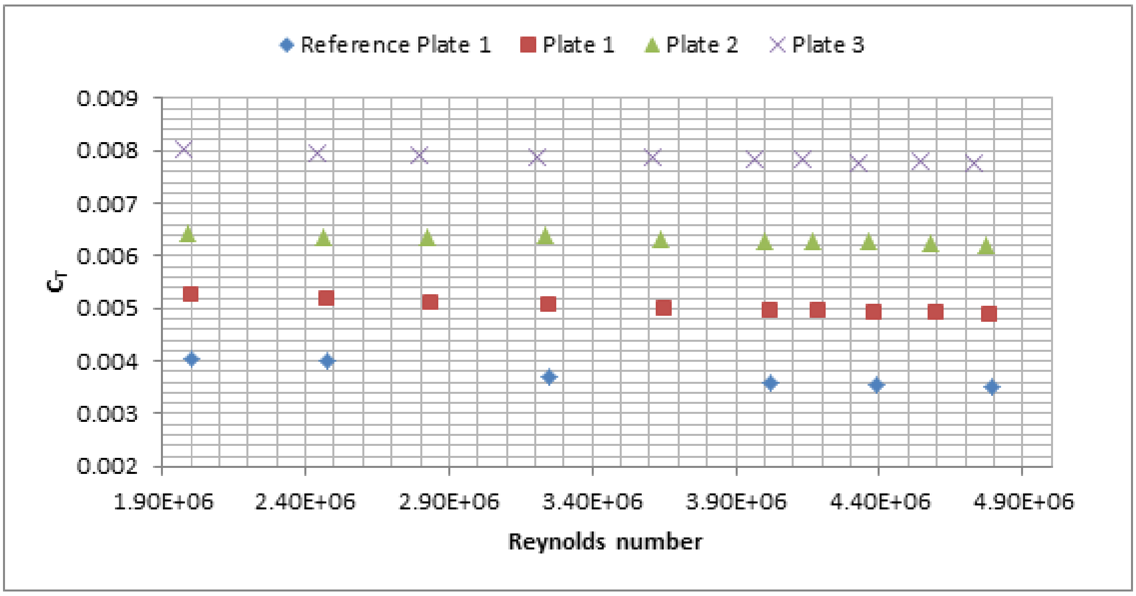


Figure 13. CT values of Reference Plate 1, Plate 1, Plate 2 and Plate 3.

Market survey of antifouling products - LRS has conducted a market survey of antifouling products from the very early stage of this task (WP10). One main purpose is to establish the control paint used in the full scale sea trial. It was also tasked to provide benchmarking criteria regarding the characteristics of current or future FOUL-X-SPEL competitors in the commercial market.

6. Techno-economic validation and technical guidelines for industry scale applications (WP11)

Achieved objectives within this task are:

- The techno-economic feasibility study of the new FOUL-X-SPEL paint was carried out and the techno-economic feasibility of the paint for different types of existing ships was demonstrated.
- Guidelines/best practices for implementation/maintenance of the coatings was developed to achieve the best performance and best industrial practices with regards to energy efficiency and environmental impact technical guidelines for industry scale applications were provided.

This task presents the techno-economic feasibility study of new FOUL-X-SPEL reference systems FXP-R1 (silicone based) and FXP-R2 (acrylic based) for different types of existing ships.

The methodology used in this study is based on several models developed in the previous tasks of FOUL-X-SPEL. Moreover, experimental results of the previous task was utilised in order to model the time-dependent fouling and drag performance.

The techno-economic feasibility studies of the antifouling paints were carried out for the following existing ships:

- Tanker
- Bulk Carrier
- Containership
- Cruise Vessel

It is of note that the ships chosen for this study are real existing ships. These ships are assumed to be coated with two main and new different types of coatings, namely FXP-N1 (silicone based) and

FXP-N2 (polyurethane based), and a third new one similar to the FXP-N2 but with just one immobilised biocide, a commercial fouling release coating (FXP-R1) and a commercial tin free self-polishing antifouling paint (FXP-R2). Therefore, it enables us to assess the techno-economic feasibility of FXP-N1 paint by comparing the life-cycle costs and emissions of the new paint with those of the existing paints. Consequently, the techno-economic feasibility study evidently highlighted the potential advantages of the use of FXP-N1 over existing reference paints in terms of economic and environmental aspects.

Table 5. The overall savings of costs and emissions due to the use of FXP-N1 (new FOUL-X-SPEL silicone bases paint with immobilised biocide) for all ships over 30 years of life-cycle.

		Reduction (%) due to the use of FXP-N1 with respect to reference commercial paints	
Ship Type	**Term**	**FXP-R1**	**FXP-R2**
Tanker	Cost	2.39	4.83
	CO_2 Emission	2.43	5.40
Bulk Carrier	Cost	1.38	3.47
	CO_2 Emission	1.41	4.02
Containership	Cost	5.68	7.18
	CO_2 Emission	5.72	7.46
Cruise Vessel	Cost	3.90	7.12
	CO_2 Emission	3.91	7.26

The developed techno-economic feasibility study methodology can easily be applied to any new antifouling coatings provided that the required data is available since the developed model includes user-defined variables. By this way the techno-economic feasibility of new coatings can be assessed by comparing the life-cycle elements of the coatings to those of the coatings assessed in this study.

Guidelines/best practices for implementation/maintenance of the coatings - Guidelines were developed based on the research results of the project, especially techno-economic analysis in the public FOUL-X-SPEL deliverable 11.2, and it will serve as the Best Practices as a Handbook for coating application and its maintenance by professionals of shipyards, ship repair yards, ship operators, surveyors as well as any subcontractors who are involved in the implementation, maintenance of the coating technology. The best practice Handbook addresses the following points for the maximum performance and cost effectiveness of the coating:

• Main functions/benefits of the coating in terms of energy efficiency, hull protection and environmental protection.

• How to prepare the hull surface for maximum performance in terms of drag reduction (energy efficiency), biocide release and durability.

• How to inspect and maintain the coating during the ship operation for high performance and durability including cleaning intervals and procedures. This will also include procedures for condition monitoring of the paint as well.

• Drydocking procedures for best cleaning, maintenance approaches as well as sequence of procedures to minimise the drydocking, maintaining the performance of coating while minimising the cost. This will help the co-ordination of the activities that involves many stakeholders.

Potential Impact

From the FOUL-X-SPEL achievements, especially from the new potential non-leaching developed antifouling coatings, it is expected to become a high contribution for ship's resistance, since the painted surface will remain smooth and durable for a longer period of time. This, in turn, implies lower fouling on the hull and lower friction resistance. Subsequently, the fuel consumption will lessen, leading to greater energy savings. All the above will open the way to "green-shipping", which means less environmental impact during voyages on sea (lower biocide impact on marine ecology) and air (lower SO_X, NOx and CO_2 emissions). This is a big step towards an environmentally friendly antifouling coating industry that would respect and preserve the marine fauna and flora, while ensuring a smooth hull.

Other expected specific impacts resulting from a potential environmental friendly antifouling coating (s) are:

- ✓ Propulsion improvement due to average drag reduction;
- ✓ Improvement of energy management by cleanness conditions of hull surface;
- ✓ Reduction of immobilization in shipyards for treatment of hull and hull repainting with conventional antifouling paints;
- ✓ Reduction on cost of hull maintenance works;
- ✓ Better shipping management concerning the availability of ship for commercial operations;
- ✓ Accomplishment of mandatory requirement of International Convention on the Control of Harmful Anti-fouling Systems on Ships;
- ✓ Save money on fuel consumption up to 30%;
- ✓ Cleaner and environmental friendly cruise ships.

In addition, to the above potential impacts, all the new developed models, extensive characterisation methodologies and protocols developed among all tasks comprised in the FOUL-X-SPEL work plan are also of high relevance for the antifouling products market. For instance, the work performed on biocide immobilisation, paints properties and performance assessment (WP2 to WP10), including life-cycle analysis and energy and environmental efficiency of paints on different ships are becoming increasingly important to assess the environmental impact and efficiency sustainability of a given coating technology. These studies, resulted models or new methodologies and strategies could serve not only internally, among the FOUL-X-SPEL Consortium, but also externally, as a theoretical/case study and practical tools, providing guidelines with regard to the methods, experimental setup and evaluation procedures that could be followed, in order to sufficiently and properly assess the performance of commercial and newly developed antifouling, multilayer coatings in all the possible aspects of environmental and service conditions an antifouling marine paint could encounter, throughout its service life.

Market potential

The primary market for the antifouling developed coating systems is the marine biofouling protective coatings market for ships. They offer a dual protective function, against hulls' deterioration and maintain ships clean from biofouling. And, since the global marine coatings industry is becoming very constrained due to the growing demanding for fuel consumption savings and the increasingly stringent environmental regulations, new eco-friendly coatings technologies will boost this global aiming, also providing high-valuable products.

The new types of coatings are also easily transferable for application in structures, for example bridges and other inland metallic structures, in coastal areas and wet zones, for both the sea and fresh water environments. This can increase its economic and environmental value, which benefit can only be evaluated based on the acceptation and evaluation on those market sectors (e.g. Power offshore, oil and Gas, Chemical Processing, Aquaculture, etc.)

The Consortium has identified relevant target groups and end-users or stakeholders, such as Ship owners, ship builders, ship operators, European shipping networks, ship management companies, port agents/authorities and key professional associations, among many others in the marine business.

In a commercial point of view and taken in account the current status of the developed FOUL-X-SPEL coating technology, their exploitation and implementation in the market depends on the performances to be achieved on Portuguese ship vessels and fuel savings on shipping operations. These field trial tests are still on-going, since and in order to constitute a business case, they should be performed for at least one-year docking period. Nonetheless, the results achieved from tested prototypes at static conditions, under different seawater conditions and biota (Southampton, Greece, Singapore, Portugal) evidenced promising performances. If the same would be proved for the coated ships under test, the next step will be to apply test areas on ocean-going vessels with extended docking intervals (3 to 5 years). Meanwhile, the launch of those formulations can be started, but its economic feasibility and acceptation on the world’s merchant fleet is somehow uncertain, because even if the novel principle of the non-leaching paint systems. On the other hand, the process may become easier and less costly if a combined strategy with other antifouling technologies is followed. This strategy is mainly suitable for the zwitterionic immobilised moieties in the Polysiloxane-based coatings. Further demonstrations and interactions between the project partners and target groups/audience will reveal the true commercial value of project outcomes in the potential markets.

Dissemination and exploitation

Dissemination and Exploitation of the Project results are essential activities to promote not only the future commercial success of new product(s) implementation. The FOUL-X-SPEL Consortium defined strategic mechanism of exploitation mainly focus on the exploitation of the paints developed and to be produced, operation for end-users, Engineering services (Consultancy, training, demonstration), software models, Education, and other future application were the developed paints are suitable.

As a whole, the FOUL-X-SPEL outcomes exploitation was planned to be achieved at four main levels, based on the main target stakeholders:

1) Exploitation by the paint manufacturer, shipyard and Service provider members of the FOUL-X-SPEL (**HEMPEL, ENP, LRS**) by offering and promoting the most advanced end-product results of the project to a wide range of their customers and to the overall shipping market through their extended portfolio of contacts which will moreover enhance the cooperation with their industrial clients and expand customer bases;

2) Exploitation by the operators (**CARN**) by improving their efficiency and environmental friendliness of their vessels by applying the developed technologies;

3) Exploitation by the universities (**IST, SU, SOUTHAMPTON and NTUA**) that will be able to transfer technology of their developments and apply in design activities while utilizing the findings in their education activities to attract more students;

4) Exploitation by Engineering consultancy companies (**ISQ** and **ENP)** and RTD (**TEKNIKER**) through making available new engineering services for tailoring performance/impact of antifouling paints in terms of environmental and energy efficiency as well as product developments for industrial applications.

These levels aim to include not only the different forms of exploitation activities (e.g. public exploitation and business exploitation), but also the social and economic impact, as well as the protection of the developed products, that means its Intellectual Property Rights (IPR).

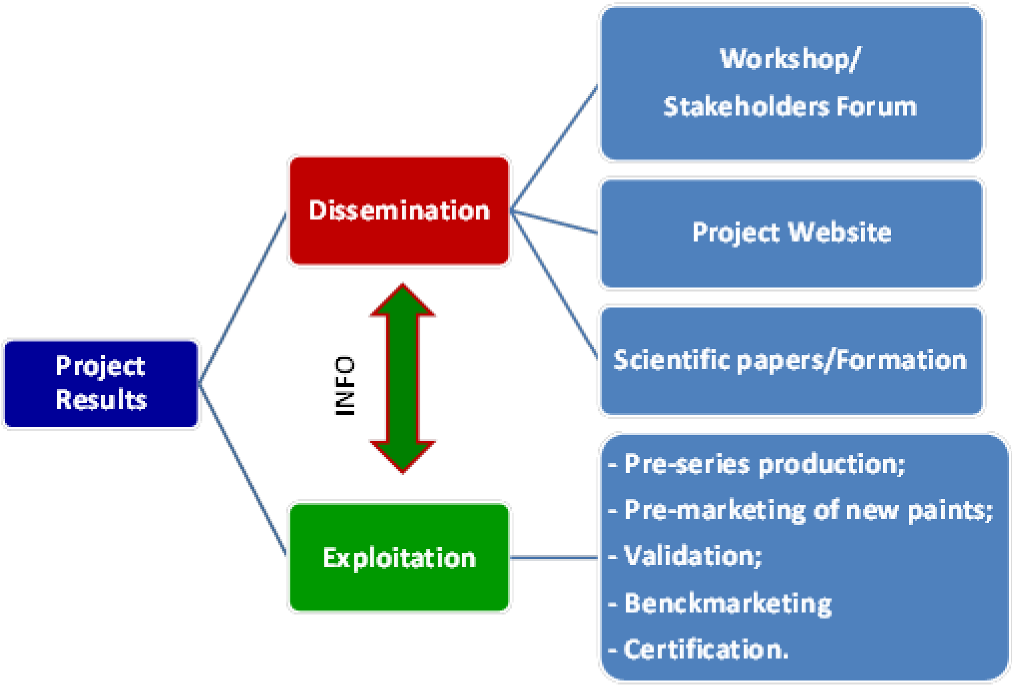


Figure 14. Road map of the project results exploitation

The FOUL-X-SPEL Consortium also evidenced that certain know-how and tools (methods, techniques, new testing machines, software models, protocols) developed in the FOUL-X-SPEL project have high potential for future exploitation and usage by different end-users and applications at public and commercial levels. The main generated outcomes have not only a high potential for future exploitation and usage by different stakeholders, but also among the FOUL-X-SPEL Consortium. Some partners had already expressed their interest to use in their institutions some of the project results, mainly for research and educational/training activities, and for collaborative work with industry, recognising the profits of their efforts performed in the project. The paint producer (HEMPEL) in particular, aims to start exploitation of the generated outcomes at different ways and levels, some can already been started in a near future, such as:

- The know-how generated for the screening and testing of coatings can be already applied in others products than the final paints from FOUL-X-SPEL;
- The studies developed regarding the impact of coatings performances on fuel efficiency of a given vessel (Modeling of energy and environmental efficiency);

- Life-cycle analysis will be used internally and externally to show case the overall environmental impact of coatings;

FOUL-X-SPEL Consortium composed by several complementary entities have their specific role on dissemination and exploitation of the generated outcomes, which were carried out in different times, places, modalities suitable to allow the promotion of project results diffusion and potential exploitation, in particular for each kind of involved entity:

a) Research institutions, regulatory class societies, ship builders and operators participate in marketing initiative trough their participation in important European exhibitions, forums, or combined events such as conferences/marketing exhibition where most attendees come from the industry maritime business. These participants can also promote the exploitation throughout their annual reports which are public.
   All these activities are periodically performed for company and institutions' marketing purposes. Therefore the exploitation of any product or tools developed by FOUL-X-SPEL can be highly promoted using these available strategic marketing mechanisms.
   For instance FOUL-X-SPEL project together with LEAF project will organize a Workshop in March 2015 – Brussels (details soon available).

b) Universities, Research & Technical Institutions were the main intervenient for project periodic results dissemination along the project duration, mainly by provided or participating in conferences, workshops, producing communication materials and uploading them to the project website, which includes demonstration work, such as Case Studies of the project results. The project website (http://www.foulxspel-antifouling.com/) is a crucial platform not only to provide communication materials from the FOUL-X-SPEL project, but also to promote communication and know-how exchange with potential stakeholders, scientific community and public in general, as a mean of the future project outputs (product, software models) marketing, as well as to promote future collaborative projects. Other institutional available platforms of the involved partners were also used to promote FOUL-X-SPEL results.

c) Education and Training: the exploitation & dissemination of project results, tools, techniques and methods developed in FOUL-X-SPEL can be also promoted and used through education and training of students and professional who desire to increase their area of expertise and acquire new skills and competences of a higher education/training level. These students and professional may become the future stakeholders and/or end-users of this project outputs. These education and training has been and will continue to be provided by:

   - Themes of doctorate, post-graduated and master projects and thesis;
   - Seminars
   - Training courses on methods, techniques and strategies for biofouling combat, monitoring and control
   - Workshops
   - Provide training for master students in the field by collaborations among the Universities and industry
   - Consultancy services
   - Promoting new national and international project proposals

These activities will attract young people to the research & development of the main issues and challenges that affects the maritime field and are sought for new and more efficient solutions, constituting one of the main priorities of the European community.

Societal Contribution

The FOUL-X- SPEL defined strategic mechanisms of dissemination and exploitation embracing different key levels, which involved not only the innovative paints developed, production and operation for end-users, but also engineering services (Consultancy, training, demonstration), software models, Education, and other future application, were the developed paints are suitable.
The contribution of the innovative technology at all those different levels will also provide improving levels of skills. The potential exploitation of the FOUL-X-SPEL results will increase the up-skilling in the area of all involved staff and systems, as well as can generate the production of new protocols, characterisation techniques, software, paint products which can create new jobs in different intervenient products route levels (marketing, distribution, production, application, training, technicians, etc.). In a preliminary stage it can mainly lead to additional training efforts of the already existent staff, but probably it will further require an additional expertise supporting for their qualification.

In addition, and since the newly technology, including antifouling paint formulations, R&D achievement (models, new derivatised biocides, etc.) can find new market opportunities in other sectors and territories, both inside and outside of the European Union, the partners will be required to undertake technology transfer and training programmes for the theoretical and technological implementation, therefore, also contributing for the technology proliferation. Moreover and as mentioned above the attraction of young people to the research & development of the main issues and challenges that affects the maritime business field sustainability and environmental are sought for new and more efficient solutions, constituting one of the main priorities of the European community.

FOUL-X-SPEL Project website: ***http://www.foulxspel-antifouling.com/***

Coordination and Technical management:

Instituto Superior Técnico (Prof. João M. Bordado and Dr. Elisabete R. Silva)

Partners:
Instituto Superior Técnico (IST)
Estaleiros Navais de Peniche, S. A. (ENP)
HEMPEL A/S
Fundacion IK4 TEKNIKER
University of Strathclyde (SU)
Instituto de Soldadura e Qualidade (ISQ)
Carnival PLC (CARN)
LLOYD'S Register EMEA
University of Southampton
National Technical University of Athens (NTUA)

4.2 Use and dissemination of foreground

Section A

TABLE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	*A CFD model for the frictional resistance prediction of antifouling coatings*	*University of Strathclyde*	*Ocean Engineering*	*Vol. 89 – 1 October 2014*	*Elsevier*	*Web*	*2014*	*pp. 21-31*	*http://dx.doi.org/10.1016/j.oceaneng.2014.07.017*	*yes*
2	*CFD approach to resistance prediction as a function of roughness*	*University of Strathclyde*	*Transport Research Arena 2014 Conference Proceedings*	*14 -17 April 2014*	*Transport Research Arena 2014*	*Paris, France*	*2014*	*Paper ID: #17875*	*http://tra2014.traconference.eu/papers/html/papers.html*	*yes*
3	*Marine Coatings: a Systematic Study on Structure-Property Relationship of Potential Covalently Immobilised biocides*	*E. R. Silva, O. Ferreira, J. C. Bordado, Ho-Chun Fang, Stuart Downie, Stefan M. Olsen*	*Transport Research Arena 2014*	*14 -17 April 2014*	*Transport Research Arena 2014*	*Paris, France*	*2014*	*Paper ID: #18102*	*http://tra2014.traconference.eu/papers/html/papers.html*	yes

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

4	*Drag reduction on recent non-releasing biocidal coatings by a newly designed drag friction test rig*	*A. V. Tulcidas, A, Igartua, J. C.M. Bordado, Stefan M. Olsen, R. Bayón, E. R. Silva*	*Tribology International*		*Science direct*	*Web*	*2015*			*No yet, submitted.recently*
5	*Evaluation of Barrier Properties of Antifouling Coatings on Naval Steel*	*E. Kiosidou, A. Karantonis, D.I. Pantelis*	*Chemical Engineering Transactions*	*Vol 41*	*The Italian Association of Chemical Engineerin g (AIDIC)*	*Italy*	*2014*	*pp. 301-306*	*http://dx.doi.org/10.3303/CET1441051*	*yes*

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[4]	Main leader	Title	Date/Period	Place	Type of audience[5]	Size of audience	Countries addressed
1	*Poster (Conference)*	*National Technical University of Athens*	*10th European Symposium on Electrochemical Engineering*	*28 September 2014 -2 October 2014*	*Chia Laguna Sardinia, Italy*	*Scientific Community*	*More than 100*	*EU*
2	*Presentation (Conference)*	*Instituto Superior Técnico*	*5th World Congress on Adhesion and Related Phenomena, WCARP-V*	*7- 11, September, 2014*	*Nara, Japan*	*Scientific Community, Industry*	*More than 1000*	*International*
3	*Presentation (Workshop)*	*University of Strathclyde*	*International Maritime Academic Collaboration Workshop*	*5 August 2014*	*Japan*	*Scientific Community, Industry*	*30*	*UK, Japan, Singapore, South Korea*

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

4	*Visit & Seminar*	*University of Strathclyde*	*International Paint*	*25 July 2014*	*UK*	*Industry*	*30*	*UK*
5	*Abstract and Presentation (Conference)*	*University of Strathclyde*	*17th International Congress on Marine Corrosion and Fouling (ICMCF)*	*6 - 10 July 2014*	*Singapore*	*Scientific Community, Industry*	*250*	*International*
6	*Presentation (Conference)*	*University of Southampton*	*17th International Congress on Marine Corrosion and Fouling (ICMCF)*	*6 - 10 July 2014*	*Singapore*	*Scientific Community, Industry*	*250*	*International*
7	*Poster (Conference)*	*TEKNIKER*	*16th Nordic Symposium on Tribology NORDTRIB*	*10-13 June 2014*	*Aarhus, Denmark*	*Scientific Community (higher education, Research)*	*More than 100*	*EU*
8	*Poster (Conference) in Outreach marketplace*	*TEKNIKER*	*Transport Research Arena Conference (TRA)*	*14-17 April 2014*	*Paris, France*	*Scientific Community (higher education, Research)*	*More than 150*	*EU*
9	*Presentation (Conference)*	*Instituto Superior Técnico*	*Transport Research Arena Conference (TRA)*	*14-17 April 2014*	*Paris, France*	*Scientific Community (higher education, Research)*	*More than 150*	*EU*
10	*Poster (Conference)*	*Instituto Superior Técnico*	*Transport Research Arena Conference (TRA)*	*14-17 April 2014*	*Paris, France*	*Scientific Community (higher education, Research)*	*More than 150*	*EU*
11	*Poster (Conference)*	*University of Strathclyde*	*11th Annual Green Ship Technology Conference*	*18-20 March 2014*	*Norway*	*Scientific Community, Industry*	*400*	*International*
12	*Presentation and Poster (Workshop)*	*Instituto Superior Técnico*	*1st CLUSTER Workshop in Materials and Nanotechnology*	*4-6 December, 2013*	*Lisbon, Portugal*	*Scientific Community (higher education, Research)*	*100*	*International*
13	*Large event*	*University of Southampton/ LLOYD'S Register*	*PSP Southampton Boat Show 2013*	*17th September 2013*	*Southampton Docks*	*Marine industry*	*2472 visitors*	*UK*
14	*Presentation (Workshop)*	*University of Strathclyde*	*Workshop on Efficient Ship Operations*	*12-13 September 2013*	*UK*	*Scientific Community*	*12*	*UK, Sweden*
15	*Poster (Conference)*	*Instituto Superior Técnico*	*European Congress and Exhibition on Advanced Materials and Processes, EUROMAT2013*	*8-13 September 2013*	*Sevilla, Spain*	*Scientific Community, Industry*	*More than 2000*	*EU*

16	*Paper (Conference)*	*University of Strathclyde*	*3rd International Conference on Technologies, Operations, Logistics and Modelling for Low Carbon Shipping*	*9–10 September 2013*	*UK*	*Scientific Community, Industry*	*70*	*International*
17	*Abstract and Presentation (Conference)*	*University of Strathclyde*	*4th UK Marine Technology Postgraduate Conference*	*11-12 June 2013*	*UK*	*Scientific Community*	*20*	*UK*
18	*Presentation (Workshop)*	*University of Strathclyde*	*Joint Workshop on Technologies to Reduce Risks in Shipping*	*3 May 2013*	*Turkey*	*Scientific Community*	*30*	*UK, Turkey*
19	*Paper (Conference)*	*University of Strathclyde*	*International Conference on Marine Coatings*	*18 April 2013*	*UK*	*Scientific Community, Industry*	*40*	*International*
20	*Poster (COST action event)*	*Instituto Superior Técnico*	*COST Action TD0906 - A focus on marine biology*	*16-19 April, 2013*	*Génova, Italy*	*Scientific Community*	*More than 100*	*EU*
21	*Poster (Conference)*	*Instituto Superior Técnico*	*Materials 2013 International Conference*	*26-27 March, 2013*	*Coimbra, Portugal*	*Scientific Community, Industry*	*1000*	*International*
22	*LR's intranet*	*LLOYD'S Register*	*Raising awareness of FOUL-X-SPEL among LRS employees*	*Since Nov 2012*	*LRS' internal intranet*	*LRS employees across the globe*	*Around 9000*	*Worldwide*

Section B (Confidential[6] or public: confidential information to be marked clearly)
Part B1

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[7]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patent-application	YES	24/02/2014	P140368EP	Dispositivo y metodo de medida de la fuerza de friccion entre un liquido y una superficie"	TEKNIKER
Patent-application	NO	06/11/2014	WO/2014/177159	Novel Polysiloxane-Based Fouling-Release Coats	HEMPEL A/S
Patent application	YES	12/12/2014	PT108096	Processo De Funcionalização De Biocidas Para Imobilização Em Matrizes Poliméricas	Instituto Superior Ténicno

[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[7] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2
Please complete the table hereafter:

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Data	*Full-scale ship trial data collected from T10.4*	*YES*	*Since 01/08/2013*	*Measurement of torque, fuel consumption, engine condition, speed, climate data, navigation data, route taken (location), ship's identity, ship's specifications and drawings*	*Marine/ shipping*	*2015* and beyond	*none*	*LRS (measurement during the trials), ENP (ship design drawings and specification), Ship owners of Mar Portuguese and Infante Dom Henrique (ship's operating data)*
Model	*Simulation model developed under T10.4/10.5*	*YES*	*Since 01/08/2013*	*Model fouling in relation to hydrodynamic resistance using the 3D-printed artificial barnacles.*	*Marine/ shipping*	*2015 and beyond*	*none*	*SU*
Data	*Panel exposure results collected from T10.4*	*YES*	*since 01/11/2013*	*Images and rating of fouling accumulated under various panel exposure tests.*	*Marine*	*2015 and beyond*	*none*	*NTUA (tests conducted in Greece), HEMPEL (test conducted in Spain and Singapore) ENP and IST (tests conducted in Portugal)*

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.
[9] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Data	*Probe test conducted under T10.2*	*YES*	*since 01/08/2014*	*Measurement of adhesion, hardness, and surface roughness.*	*Marine*	*2015 and beyond*	*none*	*IST, NTUA and TEKNIKER*
* *Commercial exploitation of R&D results*	*New test rig manufactured to perform drag friction tests on organic coatings*	*NO*	*24/02/2014*	*MRI equipment*	*Surface coatings for marine applications*	*2015*	*One patent*	*TEKNIKER (owner)*

In addition to the table, please provide a text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)

Explanation of the exploitable Foreground

- *Full scale ship trial data collected from T10.4.:*

1. Dock and underwater inspection of paint application and hull coating conditions evolved over time.
2. Hydrodynamic or energy performance of the two lone liners measured during reciprocal trials conducted in the same geographic location.

- *Simulation model developed under T10.4/10.5*

This refers to the simulation of hydrodynamic resistance of ships applied with antifouling coatings over time. The simulation model is based on the data collected from full scale ship trials in T10.4, review of various dry-dock reports, and flat plate towing tank test using 3D printing to simulate artificial fouling species attached on a ship hull.

- *Panel exposure results collected from T10.**1***

Panel exposure tests were conducted for various antifouling products at an extended period of time to identify the better FOUL-X-SPEL paint formulations in a real ocean environment.

- *Probe test conducted under T10.2*

The novel antifouling paints developed in FOUL-X-SPEL project were and will be continuously characterised, mainly in terms of their basic properties, environmental compatibility, mechanical resistance, antifouling performance on developed prototypes. The main aim is to tailoring and validate the developed formulations with the technical requirements for a final and commercial antifouling marine paint.

- *New test rig manufactured to perform drag friction tests on organic coatings*

The new test rig developed in the frame of FOUL-X-SPEL project allows to determine the drag force and drag friction coefficients of organic coating in relive motion against seawater

The new device and the testing protocols developed for performing drag friction tests will allow TEKNIKER to offer addition surfaces characterization services to the national and EU companies involved in marine and offshore applications. New potential customers interested in drag friction studies.

4.3 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	285552
Title of Project:	Environmental Friendly Antifouling Technology to Optimise the Energy Efficiency of Ships
Name and Title of Coordinator:	Professor João Carlos Moura Bordado

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? * If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
* Did the project involve children?	
* Did the project involve patients?	
* Did the project involve persons not able to give consent?	
* Did the project involve adult healthy volunteers?	
* Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
* Did the project involve Human Embryos?	
* Did the project involve Human Foetal Tissue / Cells?	
* Did the project involve Human Embryonic Stem Cells (hESCs)?	
* Did the project on human Embryonic Stem Cells involve cells in culture?	
* Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
* Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
* Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
* Did the project involve research on animals?	
* Were those animals transgenic small laboratory animals?	

* Were those animals transgenic farm animals?	
* Were those animals cloned farm animals?	
* Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
* Did the project involve the use of local resources (genetic, animal, plant etc)?	
* Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	No
* Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leaders	16	18
Experienced researchers (i.e. PhD holders)	15	20
PhD Students	2	8
Other	10	5

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**10**
Of which, indicate the number of men:	5

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?	○ x	Yes No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective				Very effective
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

x No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

x Yes- please specify: Open day of Science research, workshops. Master students.

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

x Yes- please specify: Master thesis, research materials published in University Website.

○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

2 Main discipline[10]:

1 Associated discipline[10]: | 2.3. Associated discipline[10]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ x	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No
○ Yes- in determining what research should be performed
○ Yes - in implementing the research
○ Yes, in communicating /disseminating / using the results of the project

[10] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- x Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- x No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs	x x x	Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid	 x x	Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	 x

13c If Yes, at which level? ○ Local / regional levels ○ National level ○ European level x International level	

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?		**5**
To how many of these is open access[11] provided?		**2**
How many of these are published in open access journals?		**0**
How many of these are published in open repositories?		**2**
To how many of these is open access not provided?		**3**
Please check all applicable reasons for not providing open access:		
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[12]: ……………		**x**
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**3**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**1**
	Other	**2**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:	
x Increase in employment, or	❑ In small & medium-sized enterprises
❑ Safeguard employment, or	❑ In large companies
❑ Decrease in employment,	❑ None of the above / not relevant to the project
❑ Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:* *11*

[11] Open Access is defined as free of charge access for anyone via Internet.
[12] For instance: classification for security project.

Difficult to estimate / not possible to quantify	❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes   x No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes   x No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

x	Press Release	❑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
x	Brochures /posters / flyers	x	Website for the general public / internet
❑	DVD /Film /Multimedia	x	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	x	English
x	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

2. FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

This report was submitted to the Commission before the final payment of the European Union financial contribution. Therefore, it includes the first received payment and the second requested payment for the second Project reporting period (under evaluation).

Report on the distribution of the European Union financial contribution between beneficiaries

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros	
Project Period	*1st*	*2nd*
1.Instituto Superior Técnico	286.019,34	221.304,06
2.Estaleiros Navais de Peniche, S.A.	65.421.77	124.955,43
3.Hempel A/S	138160,55	159.219,69
4.Fundacion TEKNIKER	91.509,34	139.429,34
5.University of Strathclyde	73.697,81	294.492,38
6.Instituto de Soldadura e Qualidade	27.776,62	128.345,19
7.CARNIVAL PLC	4.153,59	1.871,02
8.LLOYD'S Register EMEA	29.947,25	79.624,46
9.University of Southampton	107.542,31	131.547,49
10. National Technical University of Athens	61.904,71	138.077,31
Total	886.133,29	1418.866,37

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros
1.Instituto Superior Técnico	507323.40
2.Estaleiros Navais de Peniche, S.A.	190377.20
3.Hempel A/S	297380.24
4.Fundacion TEKNIKER	230938.68
5.University of Strathclyde	368190.19
6.Instituto de Soldadura e Qualidade	156121.81
7.CARNIVAL PLC	6024.61
8.LLOYD'S Register EMEA	109571.71
9.University of Southampton	239089.80
10. National Technical University of Athens	199982.02
Total	2304999.66