## INTRODUCTION

In the 1990's, the European marine engine makers and sub-suppliers enjoyed market success and were strong financially, unlike the European shipyards which had difficulties. After a phase of consolidation with company takeovers, mergers and acquisitions, two groups emerged, MAN and WARTSILA, which held 90% of the world's market in marine engines. The good economic results meant that they could own-fund R&D and in addition the competition between the groups meant that they would not readily consider collaborative projects with external (e.g. European Union-EU) funding – as was commonplace in the European automotive or aerospace industry.

In the past EU programmes for R&D, namely Framework Programmes FP3, 4 and 5 (1990-2002) there was no formal slot for large engines in any R&D Workplan, since there was no large-engine industry common position and related expression of interest or lobbying. In 1998 the EC established an External Expert Advisory Group (EAG) in Land Transport & Marine Technologies to advise on the R&D priorities of these sectors. The final report of this Group, part of which was later included in a European Commission White Paper on Transport Policy, recognized the strategic importance of the European large-engine industry and paved the way for inclusion of the related R&D in the EU FP6 Workplan. The new concept of Integrated Projects having large size and complexity and eligible to receive substantial funding was introduced in FP6 (2002-2006). This was instrumental in providing a sensible framework for handling the complex interrelated R&D needs of large-engine development.

Around the year 2000 there was a downturn in the marine engine industry in Europe. Intensifying the R&D activity was considered an important recovery parameter. By the year 2000 the emissions issue was also becoming important, in anticipation of pending worldwide legislation. Since the mid 1990's all engine manufacturers had ongoing research programs for low emission diesel engines and already there were some installations of prototype after-treatment systems onboard ships. In 2001 the idea of a large scale cooperative R&D project on Marine Engines was discussed between the major engine makers at the sidelines of the CIMAC World Congress in Hamburg. This project was modelled on the aerospace project EEFAE, Efficient & Environmentally Friendly Aircraft Engine, which had started in 2000 with all the major aero industry firms participating and with a 100M EUR budget, funded by the European Union.

In 2002, high-level deliberations started between MAN and WARTSILA with a view of establishing a common thematic set for a joint R&D programme on large engine technologies. By teaming-up there was also possibility of support by the European Union. In the year 2003, a common long-term R&D programme was put forward, planning for 10 years duration and 100 Million EUR research budget, to develop new technologies for marine engines, with general aims:

1) Increase engine efficiency, thus reduce fuel consumption and CO2 emissions,
2) Reduce gaseous & particulate emissions,
3) Increase engine reliability.

The R&D Programme HERCULES is the outcome of that joint vision by the two major European engine maker Groups MAN and WARTSILA. The HERCULES programme was the first time that these two groups participated together in a project with commonly defined research areas, whilst independently maintaining their specific product development targets.

## THE HERCULES PROGRAMME

The three main themes, to increase engine efficiency to reduce emissions, and increase engine reliability have been the cornerstones of the HERCULES series of projects on large engine technologies. In the year 2004, the Integrated Project HERCULES-A (High Efficiency Engine R&D on Combustion with Ultra Low Emissions for Ships) commenced. It was the Phase I of the HERCULES R&D programme. The HERCULES-A, involved 42 industrial & university partners, with a budget of 33M€, partly funded by the European Union. The project was broad in the coverage of the various R&D topics and considered a range of options and technologies in improving efficiency and reducing emissions. [1].

HERCULES-B was the Phase II of the Programme, from 2008 to 2011, with 32 participant organizations and 26 M€ budget, again partly funded by the European Union. The general targets for emissions and fuel consumption were retained in HERCULES-B. However, based on the developed know-how and results of HERCULES-A, it was possible to narrow down the search area, to focus on potential breakthrough research and to further develop the most promising techniques for lower specific fuel consumption (and CO2 emissions) and ultra-low gaseous and particulate emissions.[2].

The HERCULES-C project (2012-2015), with 22 participant organisations and 17 M€ budget partly funded by the European Union, was the Phase III of the HERCULES programme and adopted a combinatory approach, with an extensive integration of the multitude of new technologies identified in Phase I and Phase II, for engine thermal processes optimisation, system integration, as well as engine reliability and lifetime. [3].

The current project HERCULES-2 with 32 partners and 25 M€ budget, partly funded by the European Union, is targeting at a future fuel-flexible large marine engine, optimally adaptive to its operating environment. The targets of HERCULES-2 build upon the achievements

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of the previous HERCULES projects, going beyond the limits set by the regulatory authorities. The project also includes several full-scale prototypes and shipboard demonstrators. Some of the integrated solutions are expected to quickly mature into commercially available products. [5].

The evolution in the thematic content of the HERCULES programme is shown in Figure 1. The Hercules-A project considered a wide spectrum of technologies in the three themes of efficiency, emissions and reliability. After assessment at the end of the project, some of these technologies were considered to be dead-ends, whilst others were selected as worth developing further, within the next project HERCULES-B. Different technologies that could be used in combination to achieve the set objectives in efficiency, emissions and reliability were grouped and integrated in the subsequent project HERCULES-C. The present HERCULES-2 project considers the issues of long term flexibility in operation and the optimum performance over the lifetime of the products.

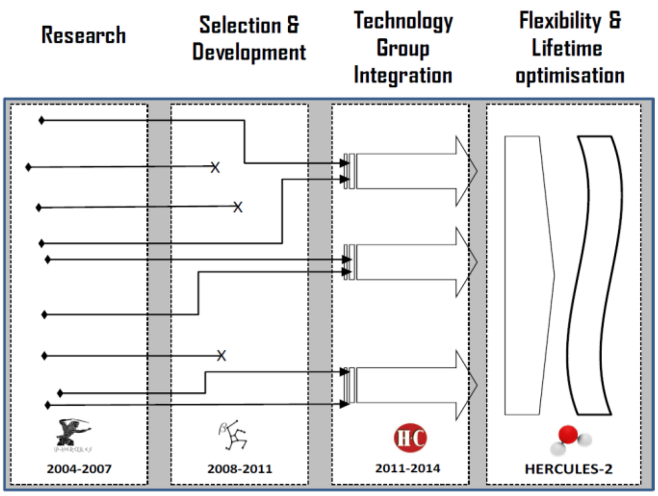


*Figure 1: From HERCULES-A, B, C to HERCULES-2*

## "SOCIAL" ENGINEERING IN HERCULES

One important aspect to be considered in HERCULES was the joint participation of major industrial players, which are competitors in the market. This joint participation could be seen as a strategic alliance "a voluntary arrangement between firms to exchange knowledge in order to develop processes or products".

The exchange of knowledge between the two major partners in HERCULES - represented by a Core Group of senior executives- initially took the form of the joint definition of the research goals of each individual project. This joint activity involved an extensive acquisition of requests from the R&D groups within each organization. The concept of Integrated-Projects introduced in EU FP6, provided a useful framework, since the development of internal combustion engines is multi-disciplinary involving fields such as thermo-fluid dynamics, combustion, materials, control. The different work needs of the various R&D groups within a company could be mapped quite well into an "integrated-project", thus the concept was readily accepted by the companies involved and thus it provided an important enabling factor for the acceptance of the overall concept. The Core Group then agreed on the priorities and consolidated the various requests into a coherent work structure, with budget for each portion as well as the total. The work was then further split into tasks and subprojects, each with budget and timing. Once this structure was finalized then the various departments or groups of major partners started to seek their third party collaborators. This selection was completely top down. Since each Core partner was fully responsible for the work and results of any specific task, this led to their choice of the best collaborators; those who would help achieve the targets of the task. This method ensured excellence in the composition of task teams and a competent lineup for the project overall.

The general management of the "alliance" was an undertaking with a relatively long learning phase. One issue to consider was the differences in Core company culture. An initial concern was how the community outside the project would perceive the apparent market dominance of the ensuing alliance. Unavoidably in the beginning there was some discomfort in co-working. The intellectual property rights-IPR of any innovations and the general market competition considerations formed sensitive concerns. Even at the very start of defining of R&D targets and budgets, there was some apprehension, lest confidential information was divulged. Eventually these issues were successfully managed, albeit with some organizational complexity. A strict Consortium Agreement was drafted with detailed rules on IPR issues. Any third party collaborator had to accept these rules before joining the project. A Project Steering committee was formed from the Core group and had complete authority on financial and work program matters. The well defined rules of engagement helped in building up confidence in the joint undertaking.

A very detailed technical annex was produced for each project. After the R&D targets were jointly defined (which in itself was a most important benefit to the participants), the core partners and their respective collaborators, were to move ahead on parallel tracks during implementation. This means that the results from each track and task were visible by the other group, but in most tasks was no joint work involving both major partners. Exception has been the basic precompetitive research, for example in tribology or materials, where joint tasks were established. Despite the apparent segregation, the visibility of results was a second major benefit. This visibility and the subsequent appraisal of successful and failed research threads from all tasks, assisted the longer term commercial planning of each major partner.

The overall timeline of the 4 HERCULES projects is presented in Figure 2. It can be observed that the sequence of the 4 projects was almost seamless.

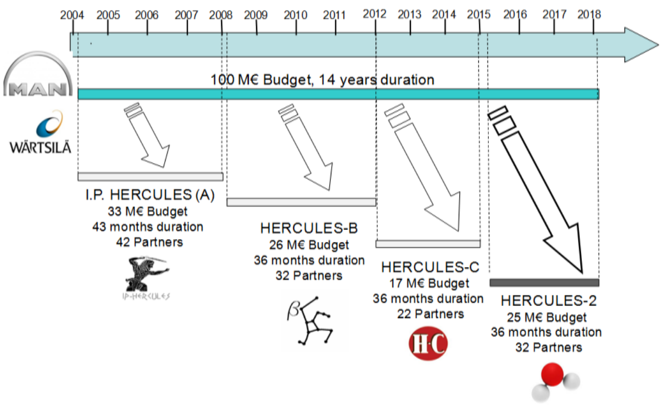


*Figure 2: HERCULES Timeline*

## METRICS OF HERCULES

The progression from each HERCULES project to the next and the links in the R&D themes are shown in Figure 3. It can be seen that starting initially with a wide spectrum of R&D areas, there was a successive filtering, combining and further development of fruitful technologies. The major themes of research namely combustion, aftertreatment, materials and control are also linked to the various workpackages of the current HERCULES-2 project.

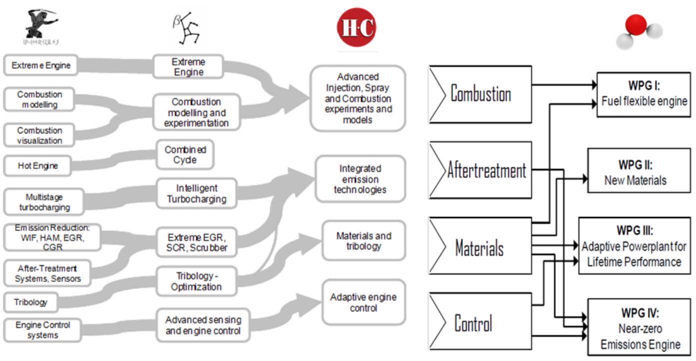


*Figure 3: Links from H-A, H-B and H-C to H-2*

The 3 completed projects HERCULES -A, -B, -C have cumulatively resulted in 38 patents applications and 91 scientific publications. Other metrics of results from the 3 completed projects, are a total of 49 prototypes, with some prototype systems tested onboard 8 ships of major operators Hapag-Lloyd, Maersk and Wallenius. A total of 18 active products resulting from the projects are presently supported commercially by the manufacturer partners. (either in serial deployment or planned for rollout after successful field test).

The evolution in numbers of prototypes from HERCULES-A to HERCULES-C is shown in Figure 4. It can be observed that the number of prototypes decreased as technologies were singled out and further consolidated. The evolution in numbers of products is shown in Figure 5. As new technologies were maturing and were implemented there is an increase in the number of products from HERCULES-A to HERCULES-C. The evolution in numbers of patents is shown in Figure 6. The initial high number of patents reflects the early-on need to protect emerging technologies. Finally the numbers of publications is shown in Figure 7.

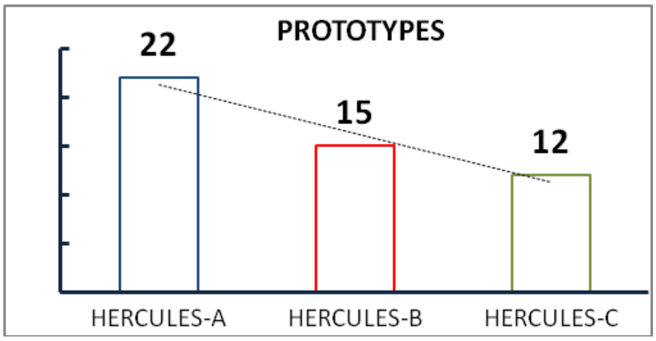


*Figure 4: Prototypes in HERCULES projects*

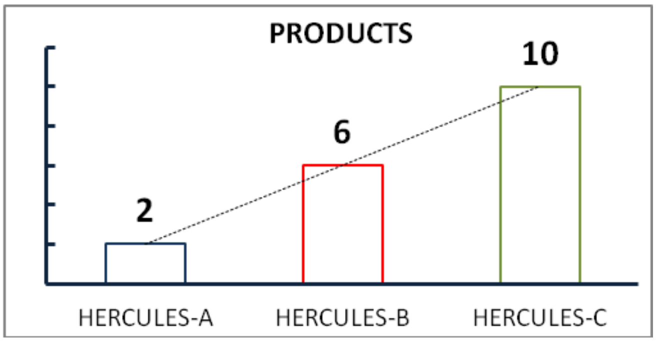


*Figure 5: Products in service from HERCULES project*

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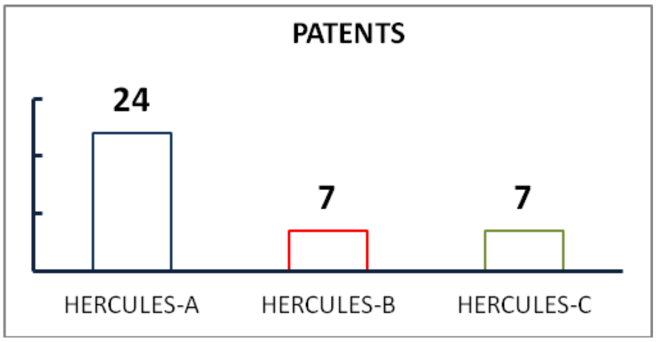


*Figure 6: Patents from HERCULES projects*

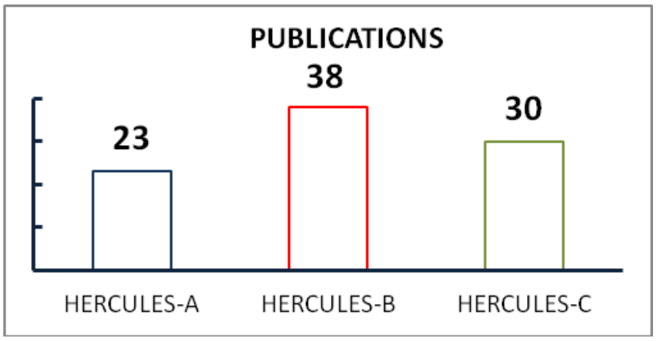


*Figure 7: Publications from HERCULES projects*

All HERCULES projects were partly funded by the European Union within Framework programmes FP6, FP7 and Horizon H2020 and the combined budget of all the 4 projects is just over 100M EUR. Overall, 86 different organizations participated in the 4 projects. In the HERCULES-A, the partner mix was (industrial/academic) = (70/30). In HERCULES-B the mix was (60/40) and in HERCULES-C (60/40). Notably this mix is changed in HERCULES-2 and it is (industrial/academic) = (30/70), with increased participation of universities in this present project. The average loaded person-month (total budget divided by total person-months) was approximately19.5kEUR for HERCULES-A, 14.0kEUR for both HERCULES-B and –C, 12.5kEUR for HERCULES-2. This reflects the up-front initial cost of the developed large scale experimental facilities and prototypes, earlier in the programme.

The percentage distribution of the total budget of each of the 4 projects into the 3 main themes of the HERCULES programme namely Efficiency, Emissions, Reliability, over the total period (2004-2016) of the programme, can be seen in Figure 8. The procedure to arrive at this thematic distribution of budget, was firstly to consider the detailed budget of each of the 189 subprojects in the programme, then to estimate the share of this detailed budget to the several technical objectives of each subproject, then to approximate the contribution of these objectives in whole or part towards the 3 main themes namely Efficiency, Emissions, Reliability and finally to consolidate the results for each of the 4 projects. It can be observed that the percent budget allocated to R&D related to Efficiency was initially quite substantial, but was reduced in subsequent projects. The main reason was the pressing budget needs of additional R&D in the theme Emissions, to cover the forthcoming legislative limits worldwide. A further contributing factor for that budget shift, was the diminishing returns when approaching efficiency close to the thermodynamic limits of the combustion engine cycle. In the latest project HERCULES-2 an increase in the budget of the theme Reliability can be observed, to address the increasing needs of work on flexibility and lifetime optimization in operation, as demanded by the end-users.

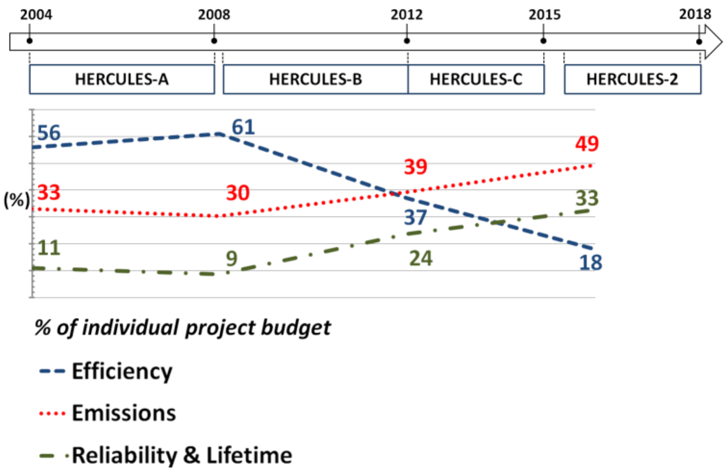


*Figure 8: Percentage allocation of budget into 3 main areas of R&D in the 4 HERCULES Projects*

## PAST RESULTS

Some of the overall results from the HERCULES programme have been very notable. The HERCULES-C project demonstrated in 2014 a 3% increase in engine efficiency and an 80% reduction in NOx emissions over the 2010 commercial Best Available Technology. A world record was also achieved: A prototype experimental large engine operating at 300 bar maximum cylinder pressure. The individual results and achievements of the completed projects have been widely published and are summarised in previous papers, such as [4].

The resulting technologies from the HERCULES programme related to the future large marine engines, are listed below:

- Multi-stage Turbocharging (+Variable Valve Timing), allowing higher performance and improved fuel consumption

- Power Take In/Out and Flexible Turbocharger (+Variable Geometry), allowing improved economy over the operating range

- Increased maximum cylinder pressure, BMEP, leading to reduced fuel consumption

- Cylinder auto-tuning & Injection optimization for improved performance, economy, reliability and emissions

- Cylinder cut-out, for improved economy

- Waste Heat Recovery from Hot Engine, for improved economy

- Selective Catalytic Reduction-SCR for exhaust NOx aftertreatment

- Water-In-Fuel, Water injection, for reduced NOx emissions

- Exhaust Gas Recirculation, for reduced NOx emissions

- Exhaust gas Scrubbers, for exhaust gas aftertreatment

- Tribology improvements and advanced Materials, for improved economy and reliability

More than 10 full scale engine experimental facilities were developed in the HERCULES projects. An example showing the typical size and complexity is in Figure 9, depicting the layout for experimental exhaust gas recirculation.

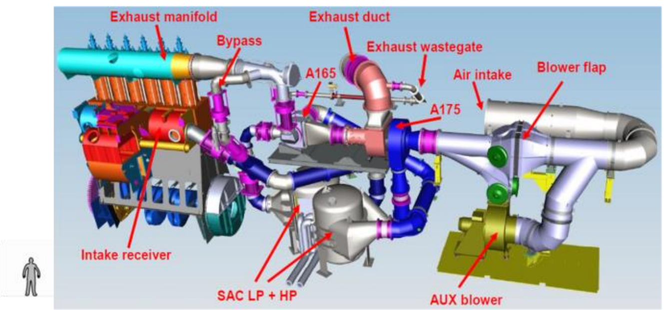


*Figure 9: Full scale experimental setup for complete variability of turbochanging system combined with EGR*

## THE HERCULES-2 PROJECT

The HERCULES-2 project takes into account: a) the increasing availability of alternative fuels and their potential contribution to the environmental and economic performance of vessels through their use in fuel flexible engines, b) the societal target of economic production of ship propulsion power with near zero emissions, c) the importance of lifetime performance optimization for new and existing ships, in the changing operational environment of global waterborne transport.

The consortium comprises 32 partners of which 30% are Industrial and 70% are Universities / Research Institutes. The Budget share is 63% Industry and 37% Universities. Two of the world's largest shipping companies shall provide ships as full-scale testing and demonstration platforms.[5].

The project HERCULES-2 contains four R&D Work Package Groups (WPG):

WPG I: Fuel flexible engine

WPG II: New Materials (Applications in engines)

WPG III: Adaptive Powerplant for Lifetime Performance

WPG IV: Near-Zero Emissions Engine

An overview of the 4 Workpackage groups in the project is schematically shown in Figure 10.

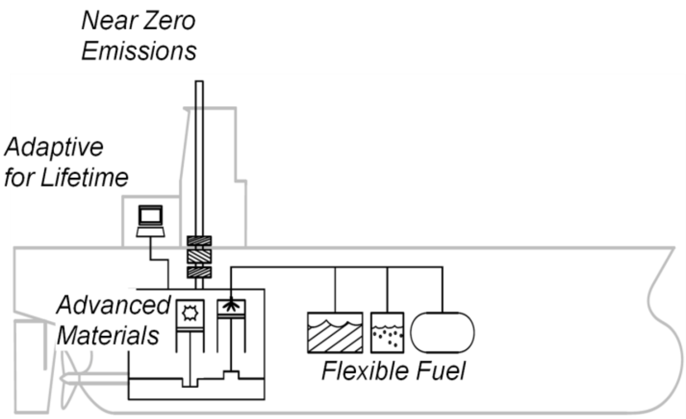


*Figure 10: HERCULES-2 Workpackage Groups*

The HERCULES-2 project Objectives are presented in Table 1. For each R&D Work Package Group, specific Objectives and actions (How) to achieve the objectives are provided.

Table 1: WPG and Objectives in HERCULES-2

| WPG | OBJECTIVE | HOW |
|---|---|---|
| Fuel flexible Engine | Seamless switching between different fuel types in a cost-effective way | -Improved understanding of injection, ignition, combustion and emissions formation<br>-Advanced test facilities with optical access<br>-Novel measurement techniques – laser illumination, high speed video<br>-Reaction kinetics enabled CFD numeric tools<br>-Closed loop control of multi-fuel injection systems<br>-Full scale tests and multi cylinder field demonstrators |
| | Complying with all emissions regulations, at all operating points, with any fuel | |
| | Improved gaseous and particulate emissions with certain fuels | |
| | Improved engine part-load performance | |
| New Materials | Facilitate improved combustion by allowing higher thermal and mechanical load | -Novel intermetallic material characterization (mechanical, physical, chemical)<br>-Integration of Thermomechanical fatigue behaviour<br>-Joining technologies investigations<br>-Heat treatment and manufacturing process investigations<br>-Selection of highly loaded engine components for test applications (cylinder head, turbocharger)<br>-Prototype manufacturing of test components<br>-Prototype components installation in test engines |
| | Enable prolonged engine operation at reduced load/speed without undue wear (hence safe and cost-effective vessel slow steaming, resulting in reduced fuel consumption) | |
| | Improved durability and engine lifetime | |
| Adaptive Powerplant for lifetime performance | Optimised performance throughout lifetime | -Predictive model based controls with adaptive and self-learning behaviour<br>-Multiple-in / Multiple-out controllers<br>-Online monitoring using advanced additional sensors<br>-Real time diagnostics<br>-Smart software-based failure detection and analysis<br>-Software-based evaluation of performance and component wear<br>-Offline tool for optimal lifetime tuning of engine<br>-Real-time tribo monitoring sensors<br>-Full scale testing of advanced optimised cylinder lubrication systems<br>-Retrofit electronic actuator for optimizing mechanically controlled engines<br>-Un-attended engine software deployment<br>-Prototype full-scale installations |
| | Reduced operating costs via optimised operation | |
| | Improved fuel consumption in transient loading | |
| | Overall fuel saving during normal operations | |
| | Advanced lubrication system with reduced lub-oil consumption and pollutant emissions (HC, CO, PM, $NO_X$) | |
| Near-zero emissions engine | Integration of After Treatment Unit (ATU) into existing engine structure in very large engines | -High pressure SCR<br>-Vibration Resistant Catalysts<br>-Closed loop emission sensing and control<br>-Optimization of fuel consumption/emissions trade-off<br>-Prototype SCR catalyst coating onto DPF substrates<br>-Deactivation and regeneration of oxi-catalysts<br>-Reduction agent, optimal injection, evaporation, reforming, mixing, analysis and experiments |
| | Combination SCR and DPF for 4-stroke large marine engines | |
| | Integration of methane slip abatement system for 4-stroke engine | |

These Work Package Groups (WPG) are expanded below:

## WP GROUP I: FUEL FLEXIBLE ENGINE

The objective of this WPG is to build engines able to switch between fuels, both conventional and alternative and of variable composition and quality, whilst operating in the most cost-effective way and complying with the regulations in all sailing regions. The fuels to be examined are different bio-fuels, DME, methanol, LNG, LPG, as well as HFO and MDO in combination with the former fuels.

In order to enable efficient engine operation on a larger variety of fuels, an increased understanding of injection, ignition, combustion and emissions formation of those novel or mixed fuels is required. Advanced test facilities with optical access, (as shown in Figure 11 ) capable of fuel flexible injection and ignition tests will be developed and operated for fundamental experimental investigations, both for low- and medium-speed diesel engines.

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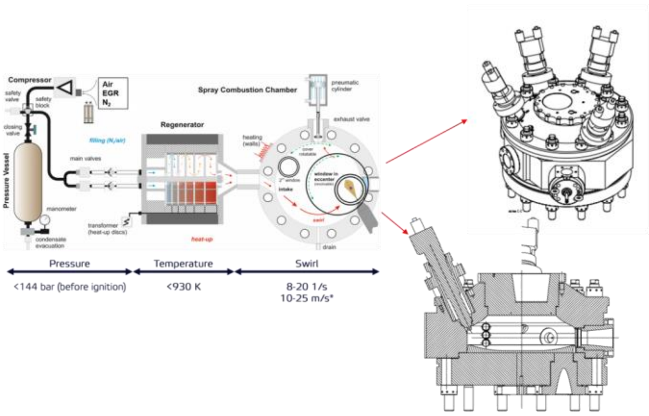


*Figure 11: Spray Combustion Chamber experimental facility for two-stroke engines*

Conventional, optical measurement techniques, such as high-speed video, as well as novel laser illumination techniques, will de developed and used. In parallel, numerical tools, such as CFD including reaction kinetics, will be created and/or adapted based on the experimental results and will be used for in-depth studying of fuel injection, spray penetration, ignition and emission formation. Novel engine control strategies such as closed loop control will be developed, to fully exploit the potential benefits of such fuels and blends. The developed fuel injection systems for multi-fuel purposes in marine diesel engines and the related control algorithms and systems, will be applied to demonstrate the fuel flexible engine operation, with full-scale engine tests in one-cylinder test engines with optical access, as well as in multi-cylinder engines (field demonstrators).

## WP GROUP II NEW MATERIALS (APPLICATIONS IN ENGINES)

The objective of this WPG is to examine the possibilities of using novel intermetallic and cast iron materials in important engine components, such as cylinder head and turbocharger turbine casing.

These new materials should enable the development of components that can withstand higher temperature and mechanical loads, hence increasing efficiency and lower emissions by providing more freedom to optimize combustion. Additionally, the WPG work will contribute to a wider operational window for marine engines, enabling also a wider range of vessel speeds. Moreover, the high wear resistance of the intermetallic materials should ensure a longer lifetime and durability of these components.

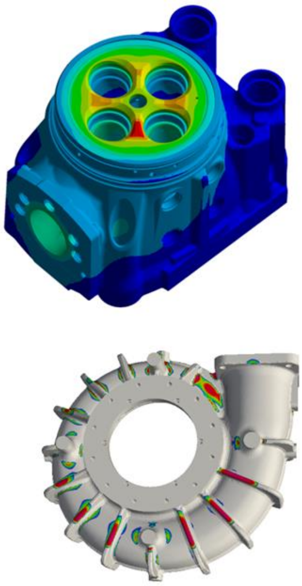

*Figure 12: New materials investigation for cylinder head and turbine casing*

Work will start with full mechanical, physical and chemical characterization as well as investigation of thermo-mechanical fatigue behaviour of chosen intermetallics and alloys, tailoring materials properties to meet the required demands for use in highly loaded components. Joining technologies, heat treatment and manufacturing processes for such materials will be investigated and if required further developed for use in selected mechanically and/or thermally highly loaded engine components (Figure 12). The capability of selected materials and technologies to cover future requirements will be validated, via manufacturing of test components and subsequent prototype testing in laboratory engines.

## WP GROUP III: ADAPTIVE POWERPLANT FOR LIFETIME PERFORMANCE

The objective of this WPG is to develop systems, methods and processes allowing for a continuous optimized performance of the powerplant, throughout its lifetime, with reduced operating and maintenance costs. The work aims at expanding the present operating range of emission reduction technologies to new operating modes. Development of novel advanced (adaptive) lubrication injection systems, as well as early detection of creeping failure modes through advanced diagnostics, will lead to reduction in operating cost and harmful pollutants. Model-based control will also lead to improved dynamic performance. An efficiency gain in transient conditions throughout the lifetime of the engine with optimal adaptive control parameters and operation points is also expected.

Based on predictive model-based controls with adaptive and learning behaviour, multiple-in / multiple-out controller will be investigated. This goal will be achieved with the help of smart software for failure detection and analysis / evaluation of performance and wear. The above advanced controls will be applied not only to steady-state operation but also in transients, manoeuvring, EGR operation, varying quality of fuel etc, thus covering the entire operating envelope of the engine.

Establishing such concepts for two-stroke engines also requires further development of the tribo-system. Parametric investigation and validation via simulation tools of the lubrication injection systems, together with development of advanced real-time tribo-system performance monitoring sensors will lead to the development of novel lubrication injection systems, which will be tested full-scale (Figure 13).

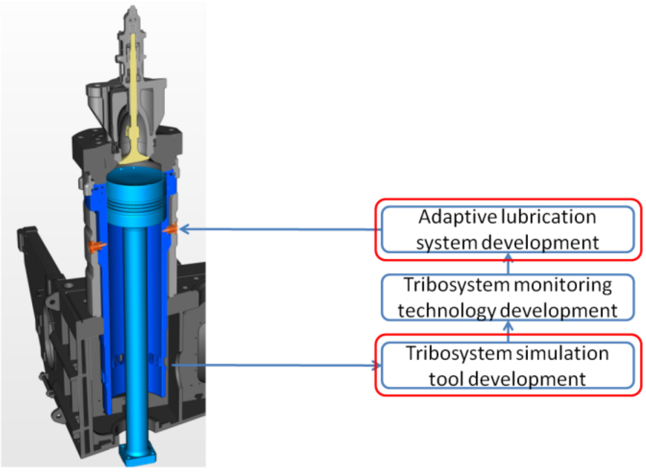


*Figure 13: Flexible lubrication system development*

In parallel, a retrofit electronically-controlled actuator for the existing mechanical fuel pump will be developed, allowing for continuous optimization of the combustion process, targeting on the existing fleet of mechanically controlled engines.

<u>WP GROUP IV: NEAR-ZERO EMISSIONS ENGINE</u>

The objective of this WPG is to achieve substantial reductions in NOx, Particulate Matter (PM) and Greenhouse gases (GHG) emission towards the "Near-Zero" emissions engine.

The work towards combined SCR with DPF for 4-stroke engines will include related feasibility studies, modelling of reduction agent spray injection, evaporation and reforming to gaseous NH3 and related experimental validation, development of control strategies, dosing system for reducing agent and sensors for feedback control. SCR catalysts which, compared to those currently used, have lower cost, higher efficiency, better tolerance for sulphur and other impurities, will be studied. Coating of DPF substrates with SCR active material will also be performed, together with evaluation of urea to ammonia conversion technologies under elevated pressure; validation of this technology will be done on test rigs i.e. urea injection test rig to study the urea evaporation and evaluate, compare and validate catalytically coated mixers, as well as DPF test rig to investigate the influence of coating on SCR performance, regeneration and PM and black carbon reduction. The above work will be supported by development of advanced, new emission measurement systems for SO3, NH3 and PM and will be full-scale validated on engine test beds. In parallel, for the lean burn 4-stroke gas engine a feasibility study will commence the work towards integration of methane abatement technology (oxidation catalysts) into the engine structure. Optimization of engine performance with the catalyst will enable a compact solution to reduce the methane slip.

For the 2-stroke engines, pre-turbocharger (High pressure) SCR systems will be considered**.**

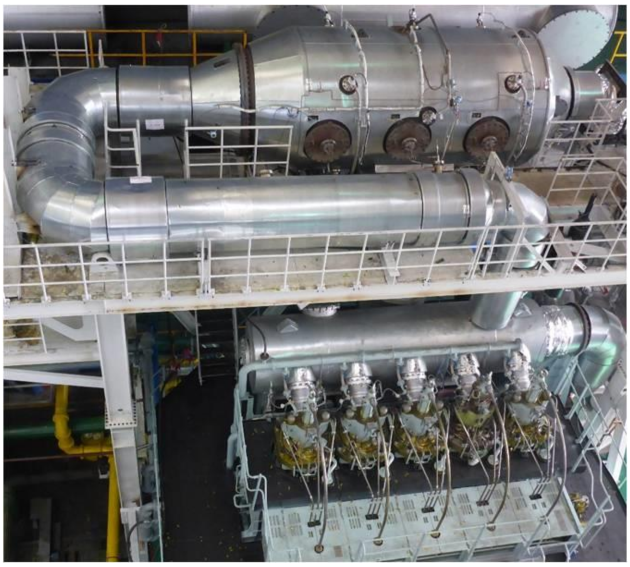

*Figure 14: Pre-turbocharger SCR system on two-stroke experimental engine*

Since the SCR system will be integrated in the existing engine structure the issues of vibration resistance and particle load requirements become important and will be investigated, leading to development in collaboration with catalyst suppliers of vibration-resistant catalyst modules, which will be tested in operation (Figure 14). The tests which will be done onboard are the vibration tests: first a clear vibration target profile needs to be determined on a vessel, later the developed SCR catalyst prototypes will need to be tested on the vessels. However, the testing of the catalysts on the vessels would need not to be attended except for mounting and dismounting. NOx emission sensors for accurate control of injection of ammonia/urea and for avoidance of ammonia slip,

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together with appropriate measurement method will be developed and experimentally validated (Figure 15).

*Figure 15: Hot exhaust gas flow test rig for testing area injectors evaporation and mixing*

The integrated SCR/DPF solutions for both 4-stroke and 2-stroke engines will be full-scale demonstrated to assess achievement of targets set.

## CONCLUSIONS

The longevity of alliances has often been used as a proxy for their performance. In that respect the HERCULES alliance, dating from 2004 till today, has been convincingly successful. In proceeding from one project to the following, the R&D areas were progressively modified, so as to consider new research directions, as dictated by the prevailing conditions and needs, but also to further expand promising technologies developed earlier. The R&D cooperation of market competitors and their suppliers, focused mainly on incremental innovations, with universities used as specialized sources of knowledge, especially in pursuing more radical innovations. The management structure of the projects was increasingly enhanced, so as to deal efficiently with the supervision of the multitude of research and administrative tasks as well as with the requirements of the funding agencies. The metrics of the completed projects indicate that the work has been quite productive. Several results of the R&D have already matured into commercial products, available in the market.

## ACKNOWLEDGMENTS

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In 2015 the Wärtsilä 2-stroke engine business was taken over by Winterthur Gas & Diesel (WinGD) a Joint Venture company between China State Shipbuilding Corporation (CSSC) and Wärtsilä. WinGD is a member of the Core Group in Hercules-2.

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