SEVENTH FRAMEWORK PROGRAMME
THEME 7: Transport (including Aeronautics)

Energy Efficiency – Technologies and clustered Research Projects

Maritime Europe Strategy Action

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TTG 1: Proposal for R&D Roadmap

Contents

Executive Summary

Content

The present report summarises the findings of MESA – TTG 1 / Energy Efficiency on technology gaps identified for Energy Efficiency Technologies in European shipbuilding and global maritime transport and lists the main research needs recognised to bridge these technology gaps.

Scope of the Gap Analysis and Proposal for R&D Roadmap

The present Gap Analysis and the Proposal for an R&D Roadmap cover the most important elements having an impact on ship energy efficiency. Based on the previous work and the findings in the State-of-the-Art report (D 1.1) technology gaps have been identified in 5 main (sub-)areas of maritime energy efficiency:

1. Hydrodynamics, Resistance & Propulsion
2. Powering
3. Emissions
4. Energy efficiency governance / EEDI
5. Energy Management - Big data / ship analytics

The gap analysis is based on material collected by the MESA Thematic Technology Group I from a variety of sources, covering EU research projects as well as other sources from both, member state based and further international research. Numerous discussions as well as the exchange with participants during the workshops (see D 1.3) and the lessons learned during those successful projects on energy efficiency which form the backbone of the showcases described in D 1.4 have led to the gap analysis described in chapter 2 of the present document and the formulation of research needs in chapter 3.

In doing so, the present report contributes to

– The Definition of strategic goals and vision in the technology area in long, medium and short term – Technology Goals;
– The Identification of technology gaps by comparing the State of the Art against the Technology Goals – Technology Gaps;
– The Identification of RDI needs in long, medium and short term based on the Technology Gap Analysis – RDI Needs;
– The Development of an Implementation Plan for the RDI Needs as an input to the WATERBORNE documents, including a prioritization and proposals for the implementation in different funding schemes – Implementation Plan.

Main Conclusions

The research and development needs in Ship / Maritime Energy Efficiency are described in chapter 3 of the present report. The key findings for the 5 main areas identified for future research and development are:

Hydrodynamics, Resistance & Propulsion

- Improvements of frictional resistance reduction through a variety of technical solutions, all considered in a life-cycle context
- Full scale validation of prediction methods for future complex simulation and optimisation concepts.
- Operational resistances and performance (power requirements) for a large range of "off-design" conditions to reliably predict the life-cycle performance of a vessel.
- Advanced propulsors concepts must be moved from lab test stage to full scale demonstration.

Powering

- Improved engine design for operation in "off-design" conditions with a special focus on advanced control strategies.
- New engine components, in particular mechanically new and advanced cooling systems
- The use of alternative fuels in the context of multi-fuel engines, the next big step will be the adoption of even more alternative fuel concepts to be run in a single engine.
- Optimisation of energy distribution, storage and peak smoothing

Emissions

- Post treatment technologies, e.g. 2nd generation scrubbers;
- Zero emission vessels – wind propulsion and its integration in advanced transport / ogistics concepts.

Energy Efficiency governance / EEDI

- Rule driven design / Uptake of new concepts into next generation EEDI formulation;

Energy Management / Big Data – Ship Analytics

- (Energy) Data acquisition and management systems
- Analysis and decision making (tools)
- Dynamic modelling and simulation tools
- Data acquisition governance

These needs result from a number of evolutionary developments of the environment in which maritime transport operates, including the evolution of the oil price as well as global legislation which is the primary driver for new developments.

1. Background and Description of work

Task 1.2 R&D Road Map updating proposal; implementation plan suggestions

Considering the strategic documents issued by the Waterborne TP and by the National Platforms task 1.2 provides a comparison of the technology status, on the scientific and implementation point of view, with the foreseen one. A gap analysis will be carried out. On the basis of these discussions among the experts and as a results of the achievements of the Thematic Workshops as well (see after) the task will define the problems to be solved in the future, the future expected achievements and the subjects that deserve a future focus of the R&D efforts. The activities will lead to the issuing of the Deliverable D.1.2 in which proposals for the updating of the Waterborne TP strategic documents will be reported. A proposal for the H2020 2016-17 work-programme is foreseen in the second year and a formal issue in the final project period. Especially the last iteration during the final period will contain a foresight exercise.

The deliverable D.1.2 will be structured along the following lines:

- Definition of strategic goals and vision in the technology area in long, medium and short term – Technology Goals;
- Identification of technology gaps by comparing the State of the Art against the Technology Goals – Technology Gaps;
- Identification of RDI needs in long, medium and short term based on the Technology Gap Analysis – RDI Needs;
- Development of an Implementation Plan for the RDI Needs as an input to the WATERBORNE documents, including a prioritization and proposals for the implementation in different funding schemes – Implementation Plan.

2. Technology Gaps

Concept

Based on the state-of-the-art technology analysis performed in the first step during the preparation of the report (chapter 2) a technology gap analysis has been performed. To put this on an even broader basis, additional work from other groups has been considered and the results of the ESSF (European Sustainable Shipping Forum) Research and Innovation group as well as the work of the relevant Vessels for the Future – VftF Assoc. – working groups has been considered.

In addition a number of external technology and foresight analyses have been considered to compare and balance the findings of the MESA group. Main sources include Lloyd's Registers' Global Marine Technology Trends 2030 Study /2/, ABS' report on Ship Energy Efficiency Measures /7/, Det Norske Veritas' Technology outlook 2020 /12/ and relevant IMO publications /8/, /9/ and /10/. A complete list of literature can be found in chapter 6.

While in some areas technology gaps can be attributed directly to the technologies described in the SotA report - chapter 2, this is not always possible, especially in view of the partly conflicting attitudes of pure energy saving (=efficiency) technologies and those primarily aimed at emission reduction (=greening). It was therefore decided to group technology gaps according to an application oriented structure which addresses main areas affecting the energy efficiency of ships and thus provides global lines of research in the future. These are:

1. **Hydrodynamics, Resistance & Propulsion**
2. **Powering**
3. **Emissions**
4. **Energy efficiency governance / EEDI**
5. **Energy Management - Big data / ship analytics**

The following chapter lists the technology gaps identified in the 5 prime areas listed above. Some of these have been addressed already either in on-going research or plans for upcoming work programmes. References to these are indicated in blue font. However, it is expected that there will be still more work to do in the future to achieve a complete solution for the solution of the problem at hand.

Missing work to bridge the technology gaps is indicated in black.

The references included in [square brackets] relate to the relevant sections in the State-of-the-Art analysis in the preceding report / deliverable D 1.1.

2.1   Hydrodynamics: Resistance and Propulsion

- [2.1.2] Viscous resistance
    - o [2.1.2.3.1] Coatings
        - § Systematic investigation of hydrodynamic properties of advanced coating systems.

- § Long term full scale analysis is required to provide reliable data for future optimised life-cycle predictions.
  - · These aspects are partly addressed in the work programme 2016/17, MG 2.1; further research will be required to assure a proper and publically available data basis.
    - o [2.1.2.4] Air lubrication:
      - § Air chambers location;
      - § Filling methods of air chambers;
      - § Prediction of bubbles dynamics (micro bubbles);
      - § Effect of air lubrication on propeller performance;
      - § Influence of seaway on the efficiency of air lubrication.
      - § Numerical models and validation.

Some development has been made in the past (FP7 – SMOOTH and other national projects), however several fundamental aspects (see above list) are still missing.

- o [2.1.2.5] Boundary layer control
  - § Active / passive stabilisation of ship boundary layer;
  - § Full scale testing of innovative concepts

These aspects are partly addressed in the work programme 2016/17, MG 2.1, further research will be required to attain a higher Technology Readiness Level. .

- · [2.1.1.3] Full scale validation of CFD predictions.
  - o Verification and Validation of CFD for non-standard conditions.
- · [2.1.3] Added resistance / ships in operation
  - o Practical prediction methods and validation; partly addressed in projects like SHOPERA [FP 7-Transport) and SYNCHRO-NET – EU project, logistics, MG 6.2, 1st call H2020, 2014.
  - o [2.1.3.2] Advanced simulation methods for reliable predictions of non-linear behaviour, validation.
  - o [2.1.4] Optimisation of Aerodynamic resistance during operation.
- · [2.2.1] Advanced propulsors:
  - o Enhanced design methods for marine propulsors;
  - o Systematic comparisons of alternative configurations;
  - o Assessing bio-mechanical propulsion.

Some development has been made in the past (FP7 – STREAMLINE and other national projects), however several fundamental aspects (see above list) are still missing

- · [2.2.1.3] POD: - electric drive train.
- · [2.2.1.3] PIDs: comprehensive analysis of performance under all operational conditions.

2.2 Powering

- · [2.3] Engines
  - o Design for off-design conditions
  - o Engine control:
    - § (1) adaptive and learning engine Control Strategies,
    - § (2) Closed loop controls for engines and integrated solutions,
    - § (3) Predictive and model based controls,
    - § (4) Engine controls, user experience and human-machine interfaces

- o Cooling:
    - § (5) Cooling system and lubrication system control, adaptive to fuel type and engine operating conditions,
    - § (6) New cooling concepts (liner, piston, cover) and cooling system arrangements. Numerical modelling of heat transfer, acid formation and acid condensation, including effects on cylinder lubrication conditions,
    - § (7) Waste energy utilisation in marine power plants. Intelligent utilisation of excess energy on Tier III engines (Smart WHR, including ORC),
    - § (8) Hybrid installations, multi-engine optimisation electrical machines integration, energy transfer and conversion, energy storage utilisation.
- o New engine components materials and their properties
    - § Corrosion, fatigue and fouling
    - § High temperature materials and corrosion material. Materials for high load.
    - § Activities would include thermal-mechanical fatigue of cast iron, resistance against hot corrosion for components in contact with exhaust gas/cooled EGR, fatigue properties and fracture mechanisms in materials used in highly loaded engine components, fatigue fretting phenomena in engine components, fatigue in welded materials, suitability of new material and coatings for engine components
- o Engine (room) design
    - § Vessels engine room: Eco-retrofitting, Integrated approach to eco-retrofit

- · **[2.3] Alternative fuels**: (in compliance with the new Commission agenda)
    - o Engine technology: Impact on Engines and Components.
    - o Fuels Benchmarking
    - o Distribution & storage:
        - § Multi-fuel fuel supply systems including material performance over life cycle, aging, fatigue and vibration issues may need analysing from point of view machinery systems ship safety
        - § Multi-fuel fuel supply systems behaviour in possible fire scenarios
    - o LCA environmental impact (safety)

- · [2.3] New systems & technologies:
    - o Assessment of (complex) ship engine / machinery systems and methods. Innovative systems-level modelling, simulation and optimisation tools to assess performance, design, retrofit solutions. (-> MG 4.3, 2nd Call), Validation of models [],
    - o demonstrating further hybrid electric, solar, wind and other radical alternative powering technologies for shipping (p 10 ff.) incl. energy harvest and storage technologies
    - o LCA of New technologies with respect to energy efficiency, emissions, safety, costs
    - o Emission / efficiency measurement / (condition based) monitoring (predictive) maintenance
        - § Develop capability to monitoring the vessel and its environment as well as on-board electrical, mechanical and thermal energy systems with distributed affordable novel sensors sometimes operating in harsh environments. Sensors could benefit from wireless and self-powered capabilities and should support

intelligent and predictive decision and monitoring support systems with real time data.

§ Develop capability of storing the collected data in a searchable and data secure environment. Develop capability such that the data can be analysed with novel and predictive data process algorithms and shared with intelligent and predictive support and visualisation systems, both on-board and on-shore. Integration with ship control room systems could be considered as well as transferring and storing data on-shore. Focus should be the facilitation of data usage on predictive maintenance and energy management, prediction and optimisation.

Develop capability to enable real time condition based predictive data driven maintenance. This requires development of vessel system and equipment intelligence through analytical modelling, experimental work and model based approach to enable novel processing and decision support systems. Prediction of future state of the machinery and structure is essential for safe and economical operation. Predictive maintenance should also cover apart from main engine and machinery the hull/propeller cleaning and dry-dock period optimisation. Impact on legislation and technical rules should be considered. Development of a demonstration platform.
FP7 transport projects RISPECT and INCASS include predictive maintenance and data collection aspects.

2.3   Emissions

- [2.3] Emission reduction technologies / scrubber
  Post Treatment Technologies -2nd Generation Scrubbers to reduce PM, application to Medium and High Speed Engine Technologies

  o Modelling tool, Calculation Method, Sensors and Control, Urea and Ammonia Cycles, Test Rig. Cost/Benefit analysis Risk assessment and Decision support tools
  o Definition of size, content, characteristic of PM, Measurement Standards, Engine process, Combustion and lubrication optimisation.
  o Compact WHR, Control system integration at engine system level, increased peak cylinder pressure, materials challenge.
  o Reliability of engines equipped with next generation of SCR, particularly integrated with engines should not decrease ship safety to a standard worse than we have now with current generation of the marine internal combustion engines.
- Emission free propulsion / wind
  o Design tools for sailing vessels,
  o Logistics concepts for operation of sailing vessels in standard trades

2.4   Energy Efficiency Governance / EEDI

- Minimum power requirement (SHOPERA in FP 7-5)
- Conceptual analysis of EEDI driven design e.g. BMT proposal of long, narrow vessels, in the context of the overall transport system (handling at sea, in ports, during passage, ...)

- Alternative formulation of EEDI (does not account for transportation time); introduce a transportation coefficient that accounts for time (-> performance).

2.5   Energy Management - "Big data" / Ship Analytics

The "Stochastics for big data and big systems" project (see page 56) aims at developing "general mathematics and statistics for understanding and modelling complex structures in time, space and networks". Further research appears to be needed to address the wide range of problems that management of such vast data poses. There are possible over-arching applications for this research in the design and operation of vessels.

- [2.6] Energy management Systems
  - o Defining tools, index and procedures for managing the energy and fuel consumption and decreasing the energy waste;
  - o Speed reduction, ultra-slow speed vessels: manoeuvrability and collision avoidance, reliability of equipment, piracy, and safety.
  - o Augmented propulsion utilizing wind and wave: ship motions, manoeuvrability (in particular in congested areas) and collision, handling in all operation phases (including launching, recovery and emergency situations), necessary minimum complementary power onboard, power management between wind propulsors and other propulsion sources, control systems reliability.
  - o Solutions for the modulation of prime movers (and their energy consumption) according to their effective load (inverters for the electric motors and/or other solutions)for different services (fans, heat exchangers, etc.); this is a key element into the operation profile of each vessel ;
  - o Optimisation of multiple engine power systems to minimise energy consumption in all modes of vessel operation
  - o Optimization of energy distribution, Storage and Peak-smoothing
  - o Efficient adoption of renewable energies e g. solar and wave, on board vessels, including safety related aspects
  - o Monitoring, control and automation devices, procedures and solution for the optimisation of energy use, power load distribution and the elimination of energy waste during the maritime operations of the different ship types in different operational conditions.
  - Trim optimisation, route planning and real time monitoring are already offered by various commercial solutions described at section 2 of this document. Research has also been carried out to improve the predictive power and reliability of mathematical models (NAVTRONIC and SeaPlanner projects, for example). More research is needed on the effect of wind and waves on delivered power (i.e. on the operation of the propeller and its interaction with the hull in such conditions). More research is also required in terms of the modelling and validation of holistic ship models.

  - o Design of new energy storage system and distribution onboard, improvement of existing systems and architecture for the storage e.g. chemical & thermal
  - o Improved energy efficiency through the use of superconducting machine, distribution and energy storage technology

- FP7 – Pose²idon, Joules, INOMANS²HIP and TEFLES address aspects of the above.

3. Research Needs and Proposal for R&D Roadmap

The Following section summarises the main findings of the work in MESA TTG 1 related to the state-of-the-art analysis and links them to the research needs which were identified in TTG 1 on the basis of technical considerations. To clarify the basis of the analysis and how the results were classified, a short description of the "System boundaries" which specify the range of the analysis is given at the start of the section.

3.1   System boundaries

Within the overall context and scope of the MESA analysis it is necessary to limit the extent of investigations performed in the EE – Group. Therefore a clear definition of what belongs to EE technologies and what not is required. Energy efficiency is an operative parameter which means that the subsequent studies will focus mainly on operational performance of ships. On the other hand, the basics for efficient operation are determined during the design of a ship. Consequently both areas need to be considered in the following.

There is a prevailing impression that "greening technologies" are often synonymous with energy efficiency. This is not always the case as certain "greening technologies" do require additional energy to perform. One such example in the context of shipbuilding are scrubbers. On the other hand, we can anticipate that all – real – energy efficiency technologies will have a positive (i.e. reducing) influence on the consumption of primary energy (fuel) on board a ship.

It was decided to limit the study to those aspects which clearly lead to reduced – primary – energy consumption during operation. If certain positive measures require substantial use of energy during production, e.g. the replacement of a component, main engine or similar, these effects need to considered too, where possible. In view of the importance of overall greening related legislation further developments for other emission reduction options, independently of their efficiency, have been considered also for future research.

3.2   SotA and Research & Development needs for selected areas of prime interest

Based on the initial structure of the work in task 1.1, i.e. the 7 sub-groups mentioned in chapter 1 and described in detail in the main body of the report chapter 3 the working group on Energy Efficiency has identified 5 main areas of prime importance:

- *Hydrodynamics, Resistance & Propulsion*
- *Powering*
- *Emissions*
- *Energy Efficiency governance / EEDI*
- *Energy Management Big Data / Ship Analytics*

Here further research and development will be necessary in the future to sustain and expand the position of Europe's maritime industry. The following tables summarise the present achievements and needs for further work, research and development in these 5 areas of prime interest.

Hydrodynamics, Resistance & Propulsion	
Importance	For the vast majority of merchant vessels, hydrodynamic effects are the prime cause of energy consumption. This holds almost entirely for cargo vessels which typically use up to 85% of all practically available energy to overcome the resistance and for propulsion. Although this picture changes completely when looking at passenger ships or other complex vessels, it must be noted that the first category of cargo vessels constitutes more than 90% of the world fleet. This makes them the prime element to further reduce energy consumption of maritime transportation.
SotA	Ship resistance is made up from two principal components, the form related pressure resistance and the viscous drag due to friction forces acting on the hull surface. During the last decade a lot has been achieved particularly to improve the pressure resistance with better hull forms, not least due to recent numerical (CFD) developments originating from earlier framework research, to the extent that today less than 20% of the overall resistance of a "good ship design" can be attributed to pressure forces. Similarly improved propulsors, either as stand-alone solutions or as multi-stage propulsors using specifically tailored energy saving devices have been shown to offer substantial increases in propulsive efficiency. Friction or viscous resistance can be influenced by surface quality and properties. Coatings are the number one element used to improve frictional resistance. After the ban of TBT paints in 2003 new coatings have been developed offering a much better environmental compatibility, though the long term surface quality has not been reached yet. Another popular means to reduce surface friction is air lubrication which has been investigated to some extent. There are different competing technological concepts around for which a full validation and proof or efficiency gains still remains open.
Gaps	Further improvements of frictional resistance (mainly on ship hulls) through the use of advanced coatings, air lubrication techniques and boundary layer control methods, all considered in a life-cycle context, are required. Full scale validation of prediction methods is considered to be of prime importance for future developments towards a complete, simulation based (hydrodynamic) design concept for all maritime vessels. Operational resistances and performance – including wind and waves – are more important to evaluate the life-cycle performance of a vessel. These are presently only roughly considered and the quality of their assessment needs to be further improved to allow for considering these aspects in next generation optimisation systems. While a number of dedicated developments for advanced propulsors have taken place already, a full validation of concepts has not been done yet. This shortcoming will hamper future developments and it should be supported by large demonstrators.

Powering	
Importance	Vessel powering is the most important (ship) function determining cost, efficiency and safety of ship operation. The by far largest share of the prime energy consumption is governed by the prime mover for more than 95% of all ships operating worldwide. The amount and choice of fuels determines the emissions and environmental footprint of these vessels.
SotA	Diesel propelled machinery is the principal and main technology used in marine propulsion today. Past research has led to High efficiency engines with optimised internal losses (friction) and increased thermal efficiency through better combustion processes and improved turbocharging. Environmental legislation further resulted in reduced emissions, either stemming from adapted internal combustion processes or external cleaning techniques like selective catalytic reduction or scrubbers. Using alternative fuels (instead of HFO) also resulted in considerable improvements in terms of emissions. The use of LNG is now widely adopted and an adequate supply infrastructure is now being established. Fuel cells which offer in principle cleaner technology have been researched to some

	extent. High cost and limited power output make it difficult today to apply the technology to shipping at a large scale. Gas turbines or nuclear propulsion either have a lower efficiency or are associated with high cost and limited public acceptance. These technologies can only be found in naval vessels today where high speeds and very high power outputs are required. Renewable energy propulsion mainly relates to wind propulsion. Several attempts have been made to re-establish sailing vessels on a small scale during the past years. A general acceptance of the technology, mainly due to its effect on scheduled services, is not apparent at the moment.
Gaps	Improved engine design for operation in "off-design" conditions with a special focus on advanced control strategies. Mechanically new and advanced cooling systems and the use of new engine components and materials for improved corrosion, fatigue, fouling and high load performance will be required plus novel concepts for engine room design to work for integrated retro-fit concepts.
	The use of alternative fuels in the context of multi-fuel engines opens a complete new field. While LNG has been widely adopted in Europe as well as international, the next big step will be the adoption of even more alternative fuel concepts to be run in a single engine. This is associated with developments addressing technology as well as logistics with a special focus on life-cycle cost and impact assessment

Emissions	
Importance	The reduction of ship emissions plays and will play an important role in the future of maritime transport. Although this is strictly speaking not an Energy Efficiency issue and hence has not been covered in the detailed analysis in chapter 3 of the present report, there are close relations with other Energy Efficiency technologies which make it appear sensible to list this part too. Despite the fact that shipping is the most efficient transport mode in terms of energy consumption the sheer size of transport work and the use of HFO call for larger effort to reduce emissions from seaborne transportation.
SotA	Emission reduction technologies and methods can be grouped into two: Primary methods are measures aimed at reducing the amount of NOX formed during combustion by optimising engine combustion parameters, Secondary methods are on the other hand designed to remove NOX from the exhaust gas by downstream cleaning techniques. For primary methods work has focused on improving combustion process, cylinder lubrication system and turbocharging; employing Exhaust Gas Recirculation (EGR) and introducing water injection. Secondary methods include the use of selective catalytic reduction (SCR), scrubbing methods (using open/closed loop, wet/dry scrubbers), non-thermal plasma (NTP) reactors, smoke/diesel particulate filters (DPF), on-board chemical CO_2 capture or pre-turbine oxidation catalysts.
	Fuel is of course decisive for the amount and quality of emissions. The use of low-sulphur diesel fuels or LNG results in significantly reduced SOX emissions. This approach is widely used today in form of dual fuel engines operating on both HFO and one of the alternative, cleaner fuels in ports and ECAs.
Gaps	Post treatment technologies like 2nd generation scrubbers will receive more attention,
	Modelling and more technical developments will be required.
	Here again, life-cycle considerations will play an important role.
	Zero emission ships – sailing vessels: appropriate design tools and the need to devise concepts for integrating sailing vessels in modern and advanced logistics concepts.

Energy Efficiency governance / EEDI	
Importance	Monitoring and control of energy efficiency standards is a vital instrument to assure the implementations of standards. The Energy Efficiency Design Index (EEDI) was made mandatory for new ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI.
SotA	The EEDI for new ships is the most important technical measure and aims at promoting

	the use of more energy efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments.
	The EEDI provides a specific figure for an individual ship design, expressed in grams of carbon dioxide (CO2) per ship's capacity-mile (the smaller the EEDI the more energy efficient ship design) and is calculated by a formula based on the technical design parameters for a given ship.
Gaps	The presently (IMO) adopted approach to the formulation of the Energy Efficiency Design Index (EEDI) will need to be revisited in the future in the light of new technical developments assuring a higher energy efficiency.
	A number of issues associated with the present formulation, including e.g. the minimum power requirement for a safe return to port and conceptual rule driven designs need an adaptation of the design index, especially in view of the overall transport work / performance adding transportation time into the equation.

Energy Management / Big Data – Ship Analytics	
Importance	A complete management of the entire energy balance on board ships is one of the main development areas promising substantial gains for the future. This is caused by the fact that the complexity of ship machinery is increasing, partly caused by the ever increasing complexity of the operational profile of many ships which need to perform efficiently under a large variety of operational conditions.
SotA	Energy management on-board ships has found significant interest over the past years, either in form of research projects or industrial developments. Several EU research projects have developed concepts and applications with often varying focus during the past 5 years. Still, a holistic solution is still missing.
Gaps	With "Big Data" being one of the buzz words in present shipping terminology, technological advances (IT) and advanced regulations (e.g. MRV guidelines) allow and require capturing a much larger amount of data relevant for the assessment and management of Energy consumption of a vessel.
	Whilst it will soon be possible to accumulate a large amount of information on fuel consumption, performance of individual components and the overall energy balance of a ship, together with operational and environmental conditions, the processing of such data will remain a challenge. A proper analysis and decision making support tools will remain the main task for future development.
	The inclusion of auxiliary propulsion, e.g. wind or other, must be considered in future energy management systems to allow for optimised consumption under varying environmental and operational conditions.
	Together with new technological developments in the respective areas, advanced solutions for energy generation (conversion), storage and distribution need to be sought to attain an optimised consumption profile.

4. RDI needs in short, medium and long term

Each of the 5 areas needing further research and development identified in chapter 3 is further detailed in the following tables. These highlight the research needs for the relevant subtopics per area over an anticipated period of 20 to 25 years, subdivided into short term (<5 years), medium (5-15 years) and long term (> 15 years) periods.

Hydrodynamics, Resistance & Propulsion					
			Short	Medium	Long
1		Friction reduction techniques (I)	Improved antifouling coatings, Patterned surfaces	Compliant coatings, Hydrophobic surfaces,	"the laminar ship"
2		Friction reduction techniques (II)	Air lubrication optimised	Combination of friction reduction techniques, gradually improving effects	
3		Full scale validation of computational techniques	Extended lab tests achieving higher Reynolds Numbers, requirements for "useful" full scale test	Set up of a high quality full scale test, Data sets.	
4		Operational Performance (Resistance, delivered Power for operational conditions)	Improved numerical methods and tools.	Integration into advanced design systems, optimisation of ship design for full operational conditions (life cycle)	
5		Advanced Propulsors	Moving laboratory design studies into full scale applications.		

Powering					
			Short	Medium	Long
1		Improved engine design for operation in "off-design"	Concepts for improved engines	Prototypes	
2		New engine components and materials	High temperature materials and corrosion material. Materials for high load	Prototype engines	More efficient engines in use.
3		Multi-fuel engines	Fuel Benchmarks Engine concept	Multi fuel engine prototypes	
4		Optimisation of energy distribution, storage and peak smoothing	Improvement of existing system and architecture for the storage. Optimization of the power load Distribution, in normal and/or peak conditions.	Design of new energy storage system and distribution onboard, especially for DC networks	Efficient adoption of renewable energies on board vessels

Emissions				
		Short	Medium	Long
1	2nd generation Post treatment technologies	Advances in combustion processes have shifted attention to exhaust gas cleaning. New materials and modelling approaches need to be developed.	Prototypes of advanced post treatment technologies, e.g. scrubbers.	
2	Zero Emission ships	Alternative ship concepts relying on emission free propulsion. Depending on public acceptance wind propulsion shall be the only viable option. - Concepts for wind propulsion / vessels - concepts for sailing vessels in an adapted global logistics chain.	Prototype vessels and application.	

Energy Efficiency governance / EEDI				
		Short	Medium	Long
1	Rule driven design	Uptake of new concepts into next generation EEDI formulation	First vessels according to novel EE design rules	
2	Update of EEDI to account for advanced technology and concepts	Energy saving designs; Minimum power requirements	Optimisation of ship designs for operational conditions – prototypes.	

Energy Management Big Data / Ship Analytics				
		Short	Medium	Long
	(Energy) Data acquisition and management systems	Higher integration level, linking of data (ship – environment);	Dynamic energy models for ships and offshore structures.	First vessels running with optimised on-board energy management systems using advanced decision making systems
	Analysis and decision making (tools)	Concepts for optimal energy management; advanced decision support systems.	Prototypes for energy management decision support systems.	
	Dynamic modelling and simulation tools	Advanced modelling tools allowing for real time simulation of energy consumption as a function of many parameters.	1st prototype applications on board.	
	Data acquisition governance	Improved ship – shore communication; Better data sampling Large data sets publically available		

5. Conclusions

The present document constitutes the findings in TTG 1 on Technological Gaps – which are based on the analysis of the State-of-the-Art analysis performed in the previous task and documented in D 1.1 – and the Research Needs in the field of Energy Efficiency which, when implemented shall help to bridge the gap between the present situation and a future, improved technological position.

The gap analysis is based on material collected by the MESA Thematic Technology Group I from a variety of sources, covering EU project research as well as open sources from both, member state based and further international research. Numerous discussions as well as the exchange with participants during the workshops (see D 1.3) and the lessons learned during those successful projects on energy efficiency which form the backbone of the showcases described in D 1.4 have led to the gap analysis described in chapter 2 of the present document and the formulation of research needs in chapter 3.

It is evident that during the past years substantial progress has been made to improve the energy efficiency of ships. This is not last due to the comprehensive work done and the achievements of a larger number of European Commission funded research projects in the past framework programmes. An important conclusion to be drawn from the analysis of the success of these projects is based on the findings of the show case report: the most successful projects evolve from a longer line of developments during which fundamentals and successive evolution of technology towards real-life applications has been achieved. The examples shown there, the engine related developments in the string of HERCULES' projects or the hydrodynamic evolution chain leading to largely improved propulsion solutions are convincing. Still it needs to be noted that there are elements missing which are central building blocks on the way to a further improved energy efficient and green ship. These are related to the 5 main areas addressed in this report:

- Hydrodynamics, Resistance & Propulsion
- Powering
- Emissions
- Energy efficiency governance / EEDI
- Energy Management - Big data / ship analytics

The associated research and development needs are described in chapter 3 of the present report. It is obvious that these needs result from a number of evolutionary developments of the environment in which maritime transport operates. An important factor is the present fuel price level which results from numerous global political and economic developments. Rules and regulations emitting from global legislation have an even bigger effect. Today's EEDI framework and especially the introduction of Emission control areas call for considerable technological changes and advances. The maritime industry has adapted to the new framework quickly, e.g. with new designs, new fuels and engine technology and – predominantly – by adopting the slow steaming concept. All this helps to achieve an better energy efficiency and a "greener" attitude of maritime transportation. What is however clear is that due to the rising complexity of requirements on ship design and operation in a much more flexible and "fluent" environment optimal solutions will be even harder to find. To progress in this respect, more effort will be necessary to develop tools and technologies which allow to implement further refined optimisation strategies for tomorrow's ships and waterborne assets.

6. Literature:

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