

4.1 Final publishable summary report

4.1.1 Executive summary

Within the JOULES project, the maritime industry has taken up the challenge to significantly reduce Greenhouse Gas emissions from shipping via the development of a design, evaluation and assessment methodology which allows for a comprehensive judgement of future design concepts.

An innovative JOULES Ship Design Methodology combining the simulation of the entire ship's energy grid with a subsequent integrated Life Cycle Performance Assessment (LCPA) has been developed. The integrated LCPA includes for the first time a holistic economic and ecological assessment methodology incl. well to tank contributions for fuel production. Detailed insight has been achieved on the complex interactions between the societies request for reduction of GHG-emissions and future innovative combinations of on-board technologies and sustainable fuels needed to comply with challenging reduction targets.

The methodology has been applied to eleven application cases in a joint effort between component and system suppliers, research and knowledge institutes, system integrators and shipyards. Information on simulation components was provided in neutral format in a central database and thus could be transferred digitally amongst the partners.. This innovative way of working through digital data sharing has enabled the involved shipyards to set-up holistic simulation models of the entire ship's energy grids which gained them novel insight and enabled them to optimize the overall energy usage and therefore efficiently reduce the corresponding emissions. Moreover, this joined effort resulted in drastic improvements in the capabilities of European shipyards and maritime suppliers to co-develop and design energy efficient ships and ship systems. This new way of working is future-proof and flexible to adapt to technologies that will emerge in the future.

Finally an economic assessment as an integrated part of the LCPA has been carried out for the eleven application cases and three demonstrator cases to identify under which constraints the developed innovative ship design concepts could be expected to be economic viable.

Following the extensive work carried out in JOULES and based on the economic and ecological information retrieved from the results, political recommendations have been worked out to support the transition from to-day's fossil fuel based shipping industry to an ultra-low emission future of shipping.

4.1.2 Summary description of project context and objectives

The JOULES-project has been initiated in the context of the strategy of the European commission to reduce CO₂ emissions, save energy and foster the uptake of renewable energies in the 20-20-20 scenario for vessels built by European shipyards. In a long term perspective up to 2050, a further significant reduction of CO₂ emissions is needed also for the maritime industry (at least 40%, if feasible 50%, acc. White Paper for Transport COM(2011) 144) to contribute for a more sustainable development.

The JOULES project is focusing on the integration of energy saving technologies in the early design stage, using advanced simulation models to be developed for the energy grid of the ship. The optimum combination of energy consumers incl. energy recovery systems is expected to significantly improve the vessels' overall energy efficiency. Technology providers, modeling experts and yard partners will work closely together to produce in total 11 application cases in 5 application areas (Ferry, Cruise Ships, Work Boats, Offshore Vessels and Cargo Vessels). The

aim is to achieve not only an emission reduction for CO₂ as stipulated in a short term 2025 scenario (appr. 23% in average for all application cases) and future 2050 scenario (appr. 50% in average for all application cases) but also to reduce other air emissions like SO_x, NO_x and PM as far as practicable at the same time.

The operating profile and in particular part load conditions were identified to provide additional potential for increase of the overall energy efficiency of ships by the simulation of the energy grid. Furthermore, the use of future alternative fuels like LNG and fuels based on renewable energies shall be addressed as already outlined in the 20-20-20 strategy. For this reason, the whole life cycle of fuels from well to propeller shall be considered and the impact on energy consumption and CO₂-emissions for fuel production (from well to tank) was identified to play an important role for the future uptake of fuels from renewable energy sources. The potential costs of such fuels play an important role for future uptake.

The results of the simulation of the ship concepts as developed in the application cases will be used for an assessment of main KPIs like Net Present Value, Cumulated Energy Demand, Global Warming Potential, Acidification Potential, Eutrophication Potential and Aerosol Formation Potential for the life cycle performance, using the LCPA (Life Cycle Performance Assessment) tool as developed in the previous EU BESST project. This tool allows for the comparison of different technical solutions taking into account various financial input parameters like fuel costs, investment costs, discount rate etc. Within the JOULES project, the LCPA tool needed to be enhanced in order to be able to use the results from the simulation of the energy grid. Furthermore, the “well to propeller” concept has been applied in the LCP assessment especially when using alternative fuels. A suitable way of representing the external costs of air emissions has been integrated in order to be able to fully compare new technical solutions with existing state of the art technologies in a holistic way.

Finally, using the results from the LCP assessment of the eleven different application cases, the most promising technologies have been further studied in 3 demonstrator cases.

The JOULES project is expected to contribute to the overall objectives by applying energy grid simulation for the 2025 and 2050 designs to increase the overall energy efficiency of European built ships. Alternative fuels including those from renewable sources are expected to play an increasingly important role over time to reduce CO₂ emissions as required. However, a holistic assessment of the future design concept is necessary and will be applied in order to identify any possible trade-offs in achieving the objectives for reduction of CO₂-emissions.

4.1.3 Description of the main S&T results/foregrounds

4.1.3.1 WG 2

Cost models

Within WP 21, a comprehensive summary of methodologies and data acquisition used for the life cycle assessment of application cases in the JOULES project has been collected and documented. It was necessary to develop a suitable LCA-methodology in the early design phase for ships together with relevant KPIs to reflect environmental impact categories for ship's emissions and use of resources. The data as available in the early design phase are limited and thus, beside the suitable LCA-methodology a comprehensive set of data has been collected in the JOULES project.

Price projections for conventional fuels have been delivered as well as rough cost estimations for future sustainable fuels from renewable energy. There is a compelling need for the shipping industry to contribute to the reduction of world-wide CO₂-emissions and the use of such sustainable fuels is offered as one possible pathway in the future to substitute existing fossil fuels producing large amounts of CO₂ during combustion.

As a result, a screening LCA methodology in line with requirement by ISO 14040 has been developed and implemented in a Life Cycle Performance Assessment-Tool, combining environmental and economic assessment for comparison of different ship designs as worked out in 11 application cases in JOULES covering a wide range of European built ship types.

As background information, all required input data for well to tank information like energy demand to produce these fuels along with the emissions during production of more than 30 types of fuels have been identified and documented in a so called "Fuel Table". This fuel table also contains the relevant physical properties of all fuels as well as cost information required for the economic assessment.

In addition, cost models have been developed for estimation of costs for equipment to be used in connection with future low emission designs. These cost models include fuel cells, batteries, abatement technologies and other equipment as used for the economic assessment in the 11 application cases.

JOULES has described methodologies and summarized the basic information needed for a holistic assessment of future innovative designs by the LCPA-Tool developed in JOULES.

Political recommendations

The societal challenge to reduce GHG-emission in the future acc. to the Paris Agreement will need substantial contributions from the maritime industry. On the other hand expected increase of global GDP with associated growth in shipping fleet makes it difficult to project required reduction. However, business as usual will increase the absolute GHG-emissions and share of total emissions dramatically over time.

The JOULES project has offered possible technical solutions and managed to model ships that comply with the objectives as outlined for the project. However, it has not been proven yet that such future ultra-low emission ships can be built. Really developing and building these innovative ships will cost a lot of time and money and there will still be risks that technologies might not be in place as required.

The following Figure 1: Political Development to support transition to zero emission ships

illustrates a possible framework for further **long term** political support to reduce GHG-emissions in practice. It can be stated that actual baseline designs using fossil fuels are impacting climate change which coincides with high external costs which are currently paid by the society. From a

technology point of view, various developments are underway being able to substantially reduce all kinds of emissions from ship (and in particular GHG-emissions) and have been theoretically applied in the 11 application cases within the JOULES project. Along with intensified R&D to make these technologies mature for integration into new built ships, the pathway towards market uptake should be supported by political action. Efficiency of future technologies (e. g. fuel cells, wind assist, energy recovery systems, energy storage technologies) as well as longevity must be substantially enhanced. Space and weight requirements are pertinent in shipbuilding and ongoing improvements are needed. At the same time the production costs for such future technology must be reduced significantly. The existing technology gaps require considerably high R&D efforts in the future.

In parallel there is a compelling need for sustainable upstream processes and land infrastructure network to be in place for the introduction of alternative / sustainable fuels in the maritime industry. The costs at which such fuels can be produced in the future are of outmost importance for a successful transition.

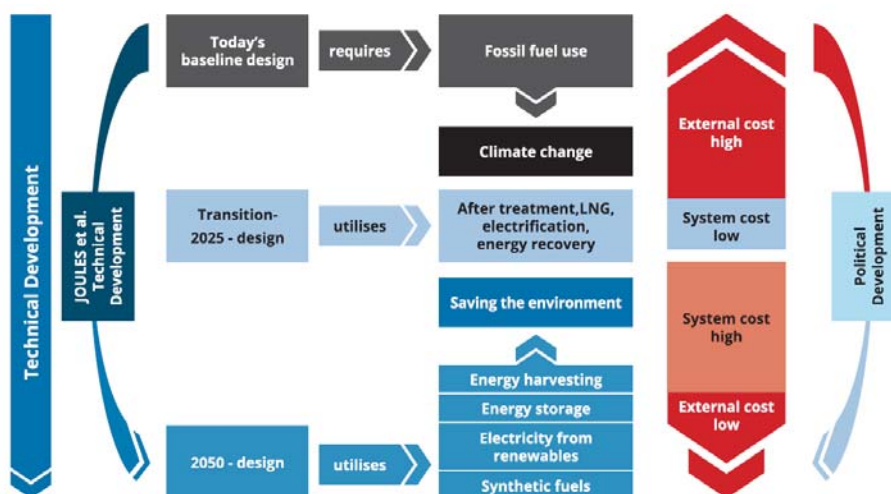


Figure 1: Political Development to support transition to zero emission ships

The long term perspective as outlined above must be complemented by a **near to medium term** perspective in order to permanently improve the overall energy efficiency of ships. Future sustainable fuels for shipping are expected to be more expensive than to-days fossil fuels and any wasting of energy on board ships must therefore be avoided. This finding is calling for a market uptake of all kinds of energy recovery systems like absorption chillers, ORC units or steam turbine generators and other items of energy saving technology (e.g. like energy efficient equipment, waste-to-energy, etc., the sum of which will have its share in the reduction target) to produce electrical energy on board ships. Technologies for energy harvesting on board like demonstrated for the Low Energy-cabin need to be considered wherever practicable. However these technologies have been proven to be not economic viable at to-days market conditions and financial incentives must be provided to allow the market uptake and full market diffusion over time.

Ships represent high investments and are operating over a long period of time. Therefore it is important that any modification on the regulatory framework is agreed on and scheduled well ahead in order to facilitate higher investments on new innovative. Wherever possible, a level playing field preferably on IMO level is recommended.

The search for optimum solutions has been proven to be really challenging and future optimum solutions from a macro-economic point of view for ultra-low emission ships might call for a future system analysis approach. This approach should cover the optimum combination of choice of sustainable fuel and on board ship technologies to combat the challenge of cost effective GHG-reductions in the future.

LCPA Tool

Introduction

The objective of the LCPA-Tool is to support a comprehensive decision making process for design alternatives in the early design stage using a sustainability approach. This includes the following categories:

- 1) The economic viability of design alternatives will be assessed using the net present value (NPV) concept as key performance indicator.
- 2) The environmental impact from construction, operating and recycling of different ship designs will be evaluated using the global warming potential (GWP). The acidification potential (AP), the eutrophication potential (EP) and the release of particulate matter (PM 10) act as key performance indicators during ship operation.
- 3) The use of resources will be attributed using the cumulative energy demand (CED) as key performance indicator. This applies for the well to tank approach for fuels, the use of relevant materials for production and energy consumption on the shipyard for building and operating of the ship. This approach ensures that all energy consumption (including their related GHG-emissions) related for production of the fuels, relevant materials and on shipyard is considered.

To increase the transparency of the cumulated energy demand, a split of fossil energy resources and renewable energy resource is preferred but could not be implemented in the current version of the LCPA-Tool due to time constraints and lack of information. In case of renewable bio-mass as feedstock for production of energy carriers, the land use as a resource is of significant influence but could also not be implemented due the same reason.

- 4) The societal impact of emissions from burning of fossil fuels is well documented and commonly known as external costs (ExterneE, NEEDS, UBA). In order to be able to internalize the effect of these external costs in the LCPA-Tool, corresponding assumptions have been made for these external costs and can optionally be linked to the Net Present Value.

The LCPA-Tool has been used to assess the 2025 and 2050 designs as developed by the WG 5 partners against the baseline designs. The quantitative prediction of values for KPIs as introduced is very much depending on ship type, operational profile, use of future alternative fuels, technology used and fuel price projections. In particular, trade-offs between the individual KPIs are expected and can be presented in a transparent way. Thus, the objective of the LCPA-Tool is to support the decision making process for design alternatives as requested for the JOULES project on an increased rational basis using important sustainability aspects.

In the projecting stage of a new ship, all relevant decisions regarding use of materials, selection of fuel type and energy efficiency of components are made until contract signing. The ship's building specification as part of the contract describes these issues in detail and is thus forming the basis also for the ship's price.

Thus, all relevant issues need to be discussed in early design stage and any assessment for the comparison of different design options has to be done in this stage. Although items may be changed after contract signing, the incurred costs for these changes will be high and most likely will not affect the principle ship's parameters but smaller design details. Figure 2 (Steen, B. 2000) illustrates this situation.

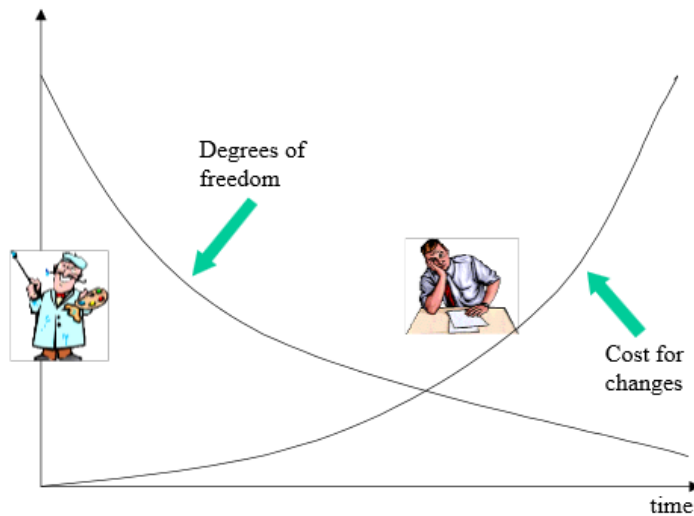


Figure 2: Challenge in early design phase

On the other hand, projecting a ship is a very complex process involving already information from many stakeholders in the early design stage, basically from the owner, operator, supplier, sub-suppliers, regulators, financial investors etc. In this respect, information might be difficult to be achieved, not finally binding or time constraints is a typical problem to overcome. Due to the complexity of a whole ship with thousands of individual components, a detailed Life Cycle Assessment (LCA) is far too much work and impossible to carry out at the early design stage. Thus the LCA as intended to be developed in the Joules Project has to deal with these restrictions and consequently, the methodology of a screening LCA is introduced. The existing LCPA-Tool has been enhanced in order to be able to also cope with this methodology and combine the economic, environmental, resource efficient and society related assessment.

In particular, three parameters are governing the future scenario of LCP-Assessment:

1. The availability of energy resources will play an increasing role in the future. Declining fossil energy resources and the need for introduction of alternative energy sources like e.g. bio-mass, wind and solar energy will put more pressure on all resources and therefore, the availability of energy resources may be restricted to a certain extent. This in particular holds for energy from bio-mass, where other purposes of use like food production or recycling purposes already exist. In addition, there will be a rivalry with other utilization in e.g. automotive- and aviation industry.
2. The price of these energy resources will heavily depend on the feedstock (in particular bio-mass, whereas wind and solar energy are “for free”) and the method of production of these alternative fuels or even renewable fuels. Many different options exist in order to produce alternative fuels (from fossil origin, bio mass or from electrical energy) like gasoline, synthetic diesel, methanol, pure methane, hydrogen and others. Some of these production plants exist in economic scale (e.g. methanol from natural gas, gasoline from coal) and provide energy carriers at an attractive price level already today. But most of the new production technologies for alternative fuels are still under development and prices for these fuels are expected to be rather high. Thus, price information is currently difficult to achieve.

On the other hand, improved conversion technologies are needed for an optimum use of energy carriers on board of a ship together with corresponding life cycle cost information which are essential for a holistic assessment.

3. The overall environmental impact (from cradle to grave) with respect to GHG-emissions will be considered in the LCPA-Tool and the key performance indicator GWP can be regarded as relevant indicator in this respect. Thus the impact for the production of the ship, the production and transportation of fuels to the ship (from well to tank) and recycling will be considered also in order to be able to decide for the best design option from an environmental point of view. Due to complexity reasons, it has been decided to restrict the calculation of the other environmental KPIs (AP, EP and PM 10) to be included only in the operational phase, although the architecture of the LCPA-Tool allows for later implementation if required.

LCP analysis

The life cycle performance assessment for each Joules application case analyses the environmental impact in combination with its profitability and the associated potential market uptake. Besides the validation of different design concepts for ultra-low emission shipping and their technical feasibility, the Joules project also examines the profitability of the design concept to evaluate the market introduction potential. Therefore, the life cycle performance assessment comprises both, the analyses of the lifecycle costs and revenues.

Before the LCPA-assessment has been carried out, the LCPA-expert developed common modelling guidelines to assure the comparability of the result. The actual LCPA of the application cases followed the same structure: Since the different ship design of the application cases have been documented in detail in WG 5, the LCPA chapters offer only a short introduction. The data input gathered from the simulation result of WG 5 and in close collaboration with the application case leaders is documented in the corresponding chapters, before each of the six KPI results is discussed in detail. Depending on the individual application cases, further analysis like GWP per NM and TEU or a sensitivity analysis is added. Every application case chapter ends with the individual conclusion of the LCPA.

4.1.3.2 WG 3

WP31 Renewables

Problem addressed

Much of the energy used on the majority of ships currently comes from non-renewable resources such as oil or gas. Not only are these resources finite, but their production and consumption also involves the emission of the greenhouse gas, carbon dioxide and other pollutants like sulphur dioxide and nitrous oxides. Renewable sources are considered alternative ways of generating energy using sustainable methods which do not run out, such as harnessing wind and solar energy.

Expected impact

Current methods for power production from renewable sources are not expected to completely replace primary conventional energy systems such as Diesel engines in the near term due to the lack of power density offered by these technologies. However, their incorporation in vessels can reduce the energy demanded from these fossil-based energy sources, and hence reduce the emissions of the overall vessel. Ships electrification using renewable energy sources could provide a zero-emission solution for short-sea-shipping. Cargo vessels in the past harnessed wind energy in the form of sails, and it is of interest to investigate wind-assisted propulsion for cargo vessels of the future, using technologies such as sails, kites or flettner rotors. Better weather prediction at sea could also offer opportunities to wind-assisted vessels, and intelligent routing to make use of wind energy could offer enhanced environmental performance benefits. In addition, several types of ships, such as Ro-Ro vessels, have large sun-exposed areas which could support the use of solar panels to allow them to produce power from the sun and supplement the ship energy grid, through the use of photovoltaic panels to generate electricity.

Project focus and results

Renewable technologies that exploit solar and wind energy have been examined as part of the project with a particular focus on cargo vessels, although other vessel types, such as cruise ships have also been considered.

Harnessing wind energy brings with it additional challenges in ship design, such as understanding possible effects at the heel of a ship and the corresponding changes to hull resistance whilst underway. A performance prediction programme for wind-assisted cargo vessels has been developed as part of the project, aimed at revealing how this technology affects the vessel and whether wind assistance for future vessels is a viable idea.

Photovoltaic panels connected to the electricity grid of the vessel have been considered and their use in conjunction with energy storage technologies, such as batteries, has also been explored to determine the benefit that solar power can offer shipping. The use of energy storage devices allows energy produced to be stored, and is of particular interest when applied to renewables, as often power production and demand do not coincide. The use of energy storage prevents energy being wasted in this situation, and instead allows the energy to be stored until needed. In addition, using a smart power management strategy, the captured renewable energy can be efficiently used when required by the ship.

WP32 Primary energy converters

Problem addressed

Primary energy converters are mainly responsible for delivering the ship's propulsion work and represent the primary form of useful power production on a vessel. Typically these are Diesel engines, which convert energy stored in fuel oil to mechanical energy, which then deliver useful work, such as turning the shaft connected to the propeller providing propulsion. They can also turn shafts connected to electrical generators, which produce electrical energy for use around the ship. The Diesel engine is a mature and well understood technology. However, recent and upcoming regulations call for improved engine designs that achieve better environmental performance when compared to older engines, which are less fuel efficient and produce emissions which do not comply with stricter emission control legislation already implemented around some areas of the world such as the Baltic Sea. The primary energy converter is responsible for the majority of energy production for a vessel, but this also means it is responsible for the majority of emissions from a vessel.

Expected impact

There are many improvements and new technologies in the latest marine Diesel engines, and these offer more power and reduced emissions compared with older engines. In addition, there are engines which burn alternative fuels, such as natural gas, and these can offer significantly reduced emissions, particularly in terms of sulphur dioxide.

Modern Diesel engines have improved capabilities achieving higher efficiency and reduced emissions compared to older engines. Developments in the field of dual-fuel and gas engines offer the advantage to power ships using cleaner fuels, including natural gas or methanol, and significantly reduce maritime emissions.

Looking further into the future, a portfolio of green technologies like fuel cells may enter the primary energy converter market as alternatives to the reciprocating Diesel engine. Low-carbon solutions will eventually improve the ship's lifecycle costs, emissions and use of resources. However, the future market diversity is expected to depend on key factors of the world's economy, such as the fuel price trends, the adequacy of bunkering infrastructures and the security of energy supply, as well as the development of regulatory pressure at global and local levels. Primary converters impact every vessel type which the JOULES project has considered, and upgrades to the primary converter or the system in which it is integrated can enable significant improvements in terms of lifecycle costs, emissions and use of resources.

Project focus and results

The JOULES project considered a number of primary converters, including medium and high speed Diesel engines, fuel cells, gas engines, gas turbines and dual-fuel engines which can burn diesel or natural gas. Each of these technologies was modelled to understand its effect on fuel consumption, energy generation and emissions for the different vessel types. Exhaust emissions were modelled to a precision that allowed a detailed understanding of the effect of using exhaust gas after-treatment technologies, and the models were produced by experienced engineers directly from a number of engine manufacturers to ensure the model performance accurately reflected reality.

WP33 Secondary energy converters

Problem addressed

In addition to improving the efficiency of the prime movers like combustion engines or fuel cells, research has been undertaken in the JOULES project on the efficiency of vessel energy system components and the reuse of waste heat. The most promising thermodynamic processes such as the Organic Rankine Cycle (ORC) were investigated. Simulation models for an oil fired boiler, a

complete steam system consisting of exhaust gas boiler, steam turbine and alternator were provided, as well as an ORC system consisting of the same main components. Whereas the steam process is a well-known technology with approved components readily available on the market, ORC is a new technology, at least on seagoing vessels. The big advantage here lies in the superior part load behaviour of ORC-systems compared to standard steam and the possibility to use heat sources at a comparably low temperature level.

Thermal energy may also be used to cover cooling loads on vessels. The absorption chiller has turned out to be the most promising technology in that respect. The simulation model makes use of engine cooling water as a source of heat and sea water as a heat sink to drive the process. The absorption technology is quite demanding in terms of the chiller unit requirements and process control but it is able to save a lot of electric energy that is consumed by the compressor chiller systems in use today.

Expected impact

Waste heat recovery systems are usually attractive for large vessels due to economies of scale. Recovery of the dissipated heat to be used in the rest of the ship represents an opportunity for larger vessels which have significant losses due to their exhaust systems and the space necessary to fit the recovery system. Energy recovered will reduce the load on the engines as they will not have to run at such high power settings to supply the vessel's energy demand, as the waste heat recovery system increases the overall system efficiency. Fuel savings from waste heat recovery mainly depend on the system size and design complexity. Yet, the installation of such systems involves certain space requirements, resulting in reduced cargo capacity.

Whilst waste heat recovery applies to larger vessels, all vessels use secondary converters, and one of the key technology areas investigated was the electric motors and generators on board, as well as other secondary converters such as lighting and heating. New technologies that have better efficiencies were investigated for all ship types being studied within the JOULES project to determine whether or not energy could be saved in each case. The hybridization of the ship's energy system with existing technologies of primary and secondary energy conversion is expected to play a significant role in future vessel design. This requires efficient power management as achieved by advanced transmission and control systems.

Project focus and results

The JOULES project considered a steam-turbine based waste heat recovery system and an Organic Rankine Cycle based waste heat recovery system for inclusion into large vessels. Other converters included induction machines, synchronous generators and permanent magnet machines for various applications including propulsion, deck machinery, power take-off and power take-in. The use of low-energy lightbulbs and LEDs, as opposed to conventional incandescent lightbulbs, were considered for vessel lighting systems and the use of waste heat, electrical and absorption chiller systems were considered as part of the heating and cooling requirements of the vessel. A technology also identified as being valuable for medium size vessels is the use of frequency controlled pumps to match the cooling water flow to the cooling demand of the ship, which can reduce the amount of electrical energy used.

WP34 Electrical distribution and energy storage

Problem addressed

Storage, distribution and electrical conversion occurs within ships to transfer useful energy from where it is produced, typically in the engines, to where it is needed, such as at the propeller, deck machinery, or electrical loads such as lighting, navigation systems or air conditioning. In all energy conversion, some energy is lost, thus requiring optimisation at an integrated level. Moreover, useful energy is often produced in quantities that do not match the requirements of the consumers.

Therefore, optimal use of the supplied power is needed so as to meet the time-variant demands in the most efficient and environmentally friendly way.

Expected impact

The expected impact depends on the vessel type. For vessels such as tugs, dredgers or cruise ships, the power requirements of a vessel change drastically based on the manoeuvres being performed, and the use of conversion and energy storage provides a huge opportunity to reduce emissions. Conventionally, multiple engines are present on these vessels, which are switched on and off based on the power requirement at a given time, at the expense of lower overall efficiency. In these scenarios energy storage can be utilised to either store excess energy, or discharge it back into the system depending on the needs of the vessel. Where this can allow a smaller installed power to allow a vessel to perform exactly the same tasks, then the use of energy storage can reduce the fuel consumption and hence emissions of a given vessel. Furthermore, models have been developed allowing designers to test and experiment with novel grid architectures, control systems and ways of directing energy around the ship in a way that maximises efficiency, safety and reliability. Energy storage and distribution systems could potentially provide smart solutions to reduce emissions and effectively cover the vessel loads.

Project focus and results

The electrical conversion and distribution components analysed via model-based techniques include transformers, converters from AC to DC and vice versa, DC to DC converters, and drives for the efficient operation of motors. Energy storage components which have been modelled include an electrically connected flywheel, batteries of different chemistries including lithium ion, and ultracapacitor technologies. Besides knowledge exchange from specialist companies to vessel designers, the JOULES project has helped with understanding the best way to utilise energy storage components as well as appreciating considerations in terms of size, safety and control.

WP35 Exhaust gas after-treatment

Problem addressed

Conventional Diesel engines produce mechanical energy from the combustion of an energy-dense fuel such as diesel oil. Conventional oil-derived fuels include compounds like sulphur and ash which are converted to gaseous pollutants during combustion. Combustion is a process that releases the chemical energy stored in the fuel, some of which is converted into mechanical energy, and some is converted to heat. As part of this chemical reaction, gaseous by-products are produced - some of them as a result of contaminants in the fuel, others due to the conditions of the combustion process. Many of these by-products are harmful to health and/or the environment, such as sulphur dioxide, responsible for acidification; nitrous oxides and particulate matter, which are responsible for respiratory health issues and environmental pollution.

As well as the use of cleaner fuels, exhaust gas after-treatment technologies could help to reduce air pollution, by removing the harmful compounds from the engines' exhaust gases. Making the right decision on selecting cleaner fuels or after-treatment systems depends not only on the ship characteristics, but also on the expected developments in fuel prices and security of supply.

Expected impact

Exhaust gas after-treatment systems can be fitted to vessels to reduce the level of emissions that are released into the atmosphere and the environment. Sulphur oxides can be removed by scrubber systems, nitrous oxides by selective catalytic reduction and particulate matter can be captured with the use of a diesel particulate filter. These after treatment systems vary in size, but can be fitted as

auxiliary systems to most Diesel engine exhaust systems to reduce the emission of these substances to the wider environment, both in port and at sea.

Project focus and results

The JOULES project has considered three after treatment technologies:

- Selective catalytic reduction (SCR) is a means of converting nitrogen oxides, also referred to as NO_x, with the aid of a catalyst into diatomic nitrogen, N₂, and water, H₂O. A gaseous reductant, typically ammonia, generated from the storage medium urea, is added to a stream of exhaust gas and then brought to the catalyst surface .
- The diesel particulate filter (DPF) is a device designed to remove particulate matter and/or soot from the exhaust gas stream.
- Scrubber systems are a diverse group of air pollution control devices that can be used to remove harmful SO_x emissions by “washing” them out and turning the acidic components to a harmless salt (for example SO_x to Na₂SO₄)

These technologies are applicable to all the vessel types considered by the project. As gaseous pollutants are of significant interest to future vessel design, the project has developed models of these systems which connect and respond correctly to the exhaust outputs of the engine models which vary with the fuel composition being burned.

From the lifecycle perspective, calculation of the performance of the emission reduction system was considered in detail in order to determine the exact improvements to the vessel that the inclusion of these systems will mean over the lifetime of the vessel. The effect of parasitic loads and additional maintenance and servicing requirements of such systems was also taken into consideration during lifecycle assessment calculations.

WP36 Consumption on board

Problem addressed

Heating, ventilation and air conditioning systems account for a significant portion of the energy demands of a modern ship, particularly in ships which carry a lot of passengers such as ferries or cruise ships. The systems control the air flow, temperature and humidity of the on-board environment to provide comfortable conditions for the crew and passengers, and also the various machinery, control systems and cargo on the vessel. Advances in technology in this area can be applied to optimise the energy use of these systems, reducing the amount of energy that the ship needs to run them.

Expected impact

Several vessels would benefit from advanced systems for on board hotel functions, with the biggest improvements likely to be seen on vessels which carry large amounts of passengers. Cabin design for cruise ships is very important, as inefficiencies, or indeed improvements in the design are analogous to the number of cabins on the ship, so even small gains in energy efficiency per cabin could quickly amount to high gains overall. There is an opportunity to optimise the heating and cooling flows around the vessel with heat transfer technology. For instance, if you can provide cooling to the engine room and heat the crew quarters by transferring this energy with technology such as heat pumps, rather than powering both heaters in the crew quarters and air conditioners in the engine room, then there is a significant energy saving available.

Project focus and results

The JOULES project has developed computer models for heating, ventilation and air conditioning systems and has implemented them in a cabin model to understand both the energy and

environmental requirements of a cruise vessel. The cabin model includes the components which are typical in the design of such a system, such as fans, heaters, coolers and dehumidifiers, and accounts for mixing, pressure loss and filtering, and thus can be adapted to a variety of different designs and applications for vessels other than just cruise ships, although it is expected that the biggest improvement in performance will be seen from the cruise vessels considered in this project.

WP37 Propulsion

Problem addressed

Propulsion deals with the efficiency of converting mechanical energy from a turning shaft, powered from an engine or motor, to provide thrust to propel a ship through the water. The design and implementation of the propulsion system and propeller can be responsible for significant losses in both the powertrain and the increased appendage resistance of the hull. Intelligent design can also reduce the required energy for a vessel to perform specific manoeuvres or actions, in order to give the vessel optimal operating performance.

Expected impact

Every vessel has a propulsion system and the operational profile of the vessel generally determines the optimal type and design of propulsion system in use. Advances in propulsion research, driven in part by advanced understanding of hydrodynamics and the widespread use of computational fluid dynamics, have led to more efficient designs being considered for state of the art vessel designs.

Different ship types benefit in different ways from different propulsors – cargo vessels which cruise at a certain speed for long time periods are likely to benefit from a direct-driven fixed pitch propeller designed to be most efficient at this cruising speed, whilst tugs require large bollard pull at very low speeds, which favours a ducted thruster. Large vessels such as cruise ships which have extensive manoeuvrability requirements to visit a number of ports on route benefit from azimuthing pods.

Project focus and results

The vast array of different vessel types and operational profiles of the project meant that a wide range of propulsion systems were considered, from the more conventional fixed and controllable pitched propellers through to azimuthing thrusters, pods, large area propellers, cycloidal and contra-rotating propulsion systems.

The project examined non-conventional propulsion at the ship design phase and quantified the benefits which might be offered in terms of improvements to the overall efficiency of the propulsion system and indeed the vessel as a whole. The project produced performance models of each propeller type with a number of adjustable parameters for designers to control the attributes and parameters of each type of propulsion system, to be able to tune them appropriately to the type of vessel being designed.

4.1.3.3 WG 4

Introduction

All information as collected in WG 4 contributes to the JOULES Knowledge Base supporting the work flow in the JOULES process. A central decision within the first period of the project was made using the FMI standard as neutral exchange format for simulation models. Furthermore developed, verified and in some cases validated models have been store in in the web based component data base for easy access through partners all developed. Finally WG 4 has developed in due cooperation with WG 2 the so called fuel table providing data necessary for simulation and LCP Assessment in the project.

FMI Standard

After having defined the principle requirements for the exchange of simulation models between partners in the JOULES project using an advanced I/O matrix, the decision has been made to use the FMI standard in this context. The FMI standard allows for the exchange of models ranging from simple models using look-up tables down to first principle models. The FMI-standard has been originally created for the application in the automotive industry however the JOULES consortium made good experience in using this standard also in the maritime industry for the first time.

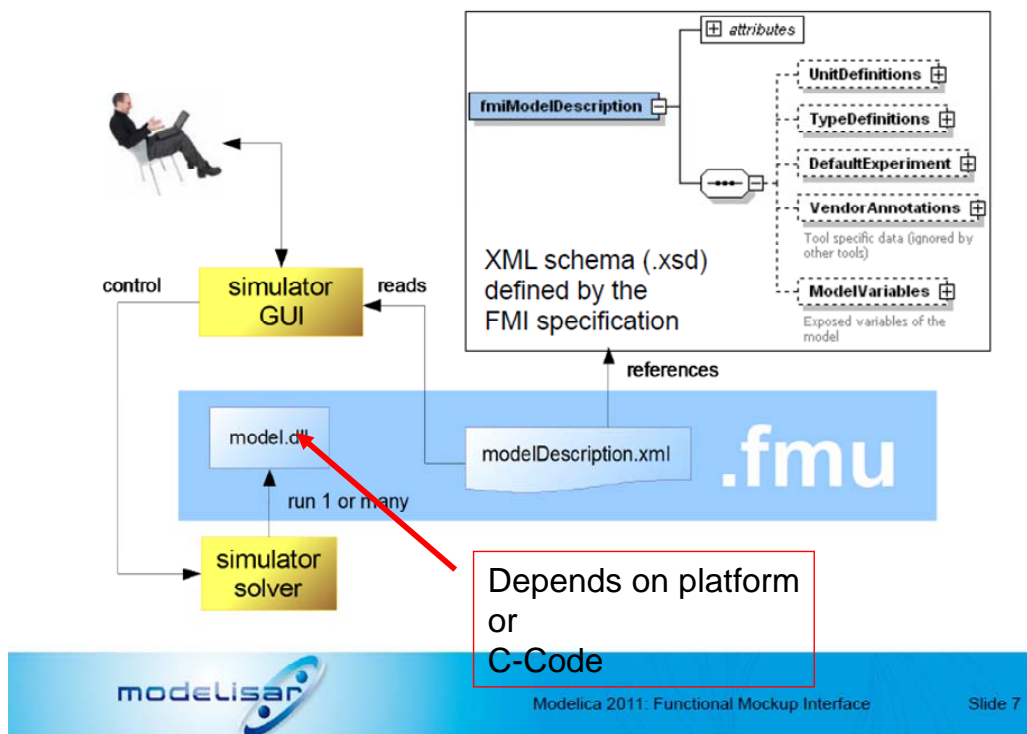


Figure 3: Exchange of Information using FMI-standard

Component Database

The JOULES Component Database (CDB) is one of the key results of the JOULES project. It serves as a central web-based CDB for two main purposes:

- Provide simulation component models based on FMI-standard for ship’s energy grid simulation
- Storage of the fuel table as consistent link between energy grid simulation and LCP-Assessment

A big number of component models have been developed and are stored in the component database. The FMI-standard allows for easy exchange between model providers and end-users for integration in ship’s energy grid. The next figure 4 provides a screenshot from this newly developed CDB.

Component	Component type	Version	Format	Supplier
Absorption Chiller	WP33 (Secondary Converters)	V8	FMU (1.0, export GES)	WNL
ASD Tug 4 55 19A Nozzle	WP37 (Consumption Propulsion)	3.0	FMU (1.0, export GES)	
ASD Tug 5 75 19A Nozzle	WP37 (Consumption Propulsion)	3.0	FMU (1.0, export GES)	
Battery	WP34 (Storage, Distribution, Elec	v16_02 v	FMU (1.0, export Simulink/Modelo	SAFT
Boiler, oil-fired (external, auxiliary	WP33 (Secondary Converters)	3	FMU (1.0, export Simulink/Modelo	USTRAT
Busbar (volt and amp to power)	WP34 (Storage, Distribution, Elec	1.0	FMU (1.0, export Simulink/Modelo	RR
Busbar Alt (power to amp and vo	WP34 (Storage, Distribution, Elec	1.0	FMU (1.0, export Simulink/Modelo	RR
Cabin	WP36 (Consumption On Board)	3.1	FMU (1.0, export Dymola)	MW
CabinWithHVAC	WP36 (Consumption On Board)	2	FMU (1.0, export Dymola)	TUHH
Cable	WP34 (Storage, Distribution, Elec	1.0	FMU (1.0, export Simulink/Modelo	RR
CourseOfADay	WP36 (Consumption On Board)	1	FMU (1.0, export Dymola)	MW
DC/DC Converter	WP34 (Storage, Distribution, Elec	3.0	FMU (1.0, export Simulink/Modelo	IMTECH
Diesel Engine High Speed (First P	WP32 (Primary Converters)	0.1.b	FMU (1.0, export Simulink/Modelo	TUD
Diesel Engine High Speed (Look-u	WP32 (Primary Converters)	1.1	FMU (1.0, export Simulink/Modelo	TUHH
Diesel Engine Medium Speed	WP32 (Primary Converters)	2.2	FMU (1.0, export Simulink/Modelo	MDT
Diesel Particle Filter	WP35 (Exhaust Gas After Treatm	2.2 (DPF_	FMU (1.0, export Simulink/Modelo	ULG
Dual Fuel Engine	WP32 (Primary Converters)	4.0	FMU (1.0, export Simulink/Modelo	WNL
Exhaust Gas Economiser (WHR1)	WP33 (Secondary Converters)	3.0	FMU (1.0, export Simulink/Modelo	USTRAT
Flywheel	WP34 (Storage, Distribution, Elec	5.0 (rev.:	FMU (1.0, export Simulink/Modelo	CCM
Fuel Cell	WP32 (Primary Converters)	1.0	FMU (1.0, export GES)	HFCS
Fuel Cell (HT-PEM, methanol fuel	WP32 (Primary Converters)	1.2	FMU (1.0, export Simulink/Modelo	TUHH
Fuel Cell + Reformer	WP32 (Primary Converters)	v3	FMU (1.0, export GES)	HFCS

Figure 4: Start Page of Component Database

Model Verification and Validation

All component models have been undertaken a verification process which has been developed according to the requirements in the project. Using the JOULES Pipeline well structured process has been established.

The JOULES pipeline

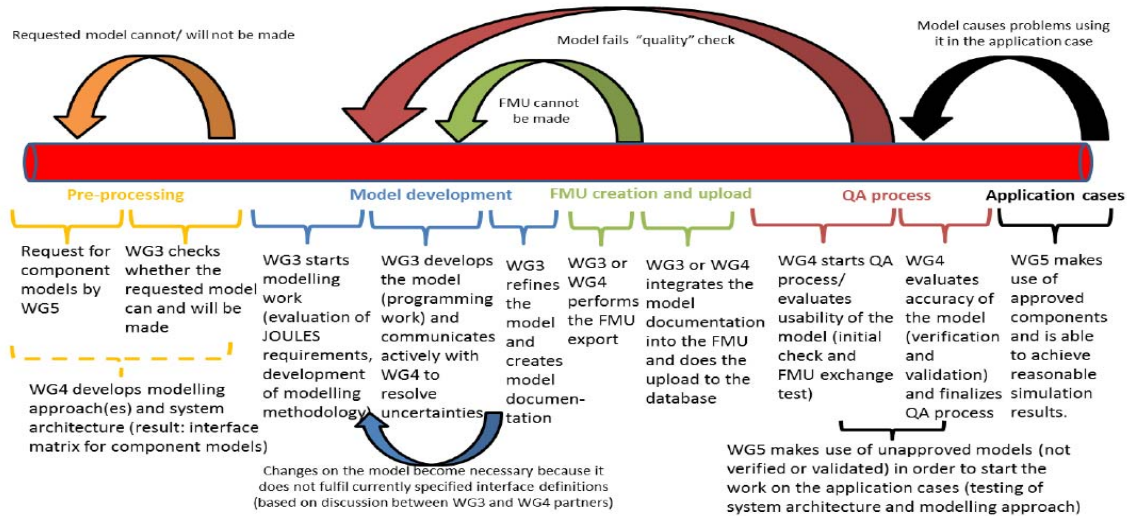


Figure 5: The JOULES Pipeline

Furthermore some selected models have been validated in an enhanced testing environment

Fuel Table

The Fuel Table as developed in JOULES contains about 35 fuels for maritime applications providing data for:

- Physical properties
- Chemical properties
- Production Data from Well to Tank (GWP, Expended Energy, NOx, SOx and PM)
- Price Projections

The Fuel Table serves for the purpose to use fuel data in the energy grid simulation of application cases (stored as Fuel FMI) and in LCP-Assessment consistently.

The following typical kinds of fuels are stored with corresponding information:

- Fossil fuels as used today in maritime industry (pink)
- Bio fuels (like Diesel or Methanol) and Upgraded Bio Gas from renewable agricultural feedstock like farmed wood or agricultural waste (orange)
- Electro-Fuels with different pathways for production (mainly different sources of electrical energy, GHG sources, central or local production (green))

The price projections for the JOULES project are based on the assumption that HFO and MGO prices correlate to crude oil prices. For the HFO, MGO, and LNG projections, the Energy Information Agency projections assumed a scenario of low economic growth, with moderate/high regulatory and stakeholder pressure according scenario "C" in (DNV GL 2015). In a similar way, a price projection for Methanol from natural gas as feedstock has been achieved.

The price projection for electro-fuels has been based on an approach using specific costs [€/kWh] as given in the literature for:

- Production of renewable energy from wind farms¹
- Hydrogen Production
- CO₂-extraction (from flue gas of existing industries or from ambient air)
- Synthesis costs (Methanation, Methanol Synthesis, Fischer-Tropsch Synthesis)
- Liquefaction where applicable (liquefied Re-methane to substitute LNG, Re-Hydrogen)
- Storage and Distribution covering the infrastructure costs
- Bunkering costs

Considering that future development of such fuels must take place to achieve the emission reduction targets, it is well known that scale effects, efficiency gains and improved utilisation of these future fuel production plants allow for a significant reduction of the production costs (represented in terms of learning curves). In the context of the JOULES project a linear drop of 50% by 2050 has thus been estimated due to a. m. effects following a more detailed analysis of a 500 MW plant for production of e-Methanol as an example.

¹ Wind Power as an example, also Concentrated Solar Power (CSP) power plants, Photovoltaik (PV) power plants, wave or tidal power plants are expected to contribute to sufficient renewable energy in the future.

4.1.3.4 WG 5

Introduction

Within the JOULES project 22 future ship concepts are developed. These concepts are related to an advanced and next generation time path, respectively 2025 and 2050. The concepts represent the so-called application cases, 11 in total. An application case refers to a vessel type typically for the European shipbuilding industry. These vessels are categorized in 5 groups: passenger, cruise, offshore, workboat and cargo. Figure 6 presents the 11 application cases with the responsible shipyard.



Figure 6: Overview of Application Cases

The common goal of these application cases is the reduction of global warming potential (GWP). The targets increase over time, so the target for the advanced design is less strict than the next generation design. Figure 7 shows the GWP reduction target for each application case. To reach these targets it is foreseen that a holistic approach to the ship energy grid is required.

Application Areas	Application Cases	2025	2050
Ferry	Ro-Pax	20%	80%
	Urban Ferry	25%	70%
Passenger Ships	Ocean Cruiser	40%	70%
	River Cruiser	15%	80%
	Mega Yacht	15%	30%
Work Boats	Tug	20%	40%
	Dredger	25%	40%
Offshore	OPV	20%	40%
	OSV	20%	40%
Cargo	Arctic Cargo	20%	40%
	Wind Assisted	35%	50%

Figure 7: High Level GWP Reduction Targets in JOULES

Baseline vessel and operational profiles

The first phase in the project is the definition of the baseline scenario. A reference vessel is selected for each application case. During the entire project the modifications and design changes are reflected with this baseline case. The baseline vessel is a state-of-the-art solution. This requirement stimulates the adoption of novel technologies and to think outside the box for the future concepts.

Next to the baseline vessel also the operation of the vessel needs to be determined. It is noticed that in general vessels operate at part load in real life. There seems to be a difference between the design and operational conditions. This is the first analysis which can be done when the operational conditions are known. The definition of an operational profile differs significantly along the application cases. The following methods are used during the project: percentage of operation mode, sailing speed, propulsion and auxiliary power, but also more detailed time traces of sailing speed are determined by measurements.

Concepts

The second phase of the project is the design of the advanced and next generation concepts. This is a combined effort of the component suppliers and shipyards. The specific component knowledge of the suppliers is combined with the integration and application experience of the shipyards. Novel technologies are integrated with a holistic approach to reach the optimum combination and size of the various components. Vessels characterized by a more constant operation focus on thorough integration of the mechanical and thermal system, while vessels with a more dynamic operation suit better with electrification.

		renewables		Primary converters				Secondary converters				Energy Storage Devices			Aftertreatment		
		Wind power system	Solar Panel	diesel	Dual fuel gas	Gas turbine	Fuel cell	ORC system	Steam system	High Efficient pump systems	Chiller systems	Battery	Flywheel	Ultracapacitor	SCR	nit scrubber	Filter
baseline	Roosk																
	Uper Ferry																
	Cash of Air																
	River cruiser																
	Waggeport																
	Tall																
	Dwager																
	CEV																
	CEV																
	Arctic cargo vessel																
2025	Roosk																
	Uper Ferry																
	Cash of Air																
	River cruiser																
	Waggeport																
	Tall																
	Dwager																
	CEV																
	CEV																
	Arctic cargo vessel																
2030	Roosk																
	Uper Ferry																
	Cash of Air																
	River cruiser																
	Waggeport																
	Tall																
	Dwager																
	CEV																
	CEV																
	Arctic cargo vessel																

Figure 8: Overview of novel Technologies selected by Application Cases

Figure 8 shows an overview of the selected novel technologies by the application cases for the baseline, advanced and next generation design. The advanced designs still rely on diesel engines, but start to incorporate waste heat recovery for power generation or absorption chillers to generate chilled water. Also the first vessels start to apply energy storage for hybrid solutions. After treatment will be needed to fulfil the near future regulations. The advanced designs tend to zero emission solution in which the fuel cell is key. Therefore after treatment can be abandoned, but energy storage becomes even more attractive due to electrification.

Simulation

The third phase of the project is the detailed simulation of the baseline, advanced and next generation design. This is the major part of the development within WG 5. The simulations are fundamental for the integration and assessment of the energy grids. Basically two methods have been followed within the project: energy grid and dynamic system modelling. These two methods are illustrated in Figure 9.

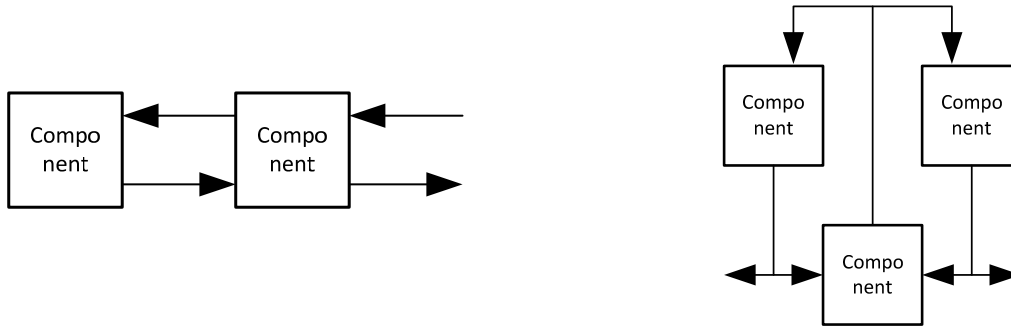


Figure 9: Basic Interface Layout of Energy Grid (left) and Dynamic System (right) Modelling

The energy grid modelling is used for large ships with extensive ship systems. Most often the waste heat from propulsion is used for HVAC and power generation. This modelling method calculates with energy flows which makes it straightforward and robust. Therefore the system overview keeps clear and the integration of the system on high level is determined.

Dynamic system modelling gives a physical representation of the system which leads to system comprehending. This is useful for the development of complex propulsion systems including the controls and energy and power management systems. Due to the high level of detail it enables integration on component level.

Within the JOULES project multiple simulation platforms are used, see Table 1.

Each yard has the preference for a certain package for all kinds of reasons. This can be user experience, price, adaptation by industry, etc. Nevertheless, each partner is able to use the same component models developed by WG3. The common shared component database is the key to success. Component models are converted to the fmi/fmu standard. This translates an open platform specific model to an encrypted platform independent model.

Table 1: Overview of simulation platforms within WG5

<i>WP</i>	<i>Description</i>	<i>Software</i>
51 a	RoPax	Dymola
51 b	Urban ferry	Matlab / Simulink
52 a	Ocean cruiser	SimulationX
52 b	River cruise	Dymola
52 c	MegaYacht	Excel
53 a	Tug	Matlab / Simulink
53 b	Dredger	Matlab / Simulink
54 a	OPV	Matlab / Simulink
54 b	OSV	Dymola
55 a	Arctic Cargo	Apros
55 b	Wind	Excel

Eventually the simulation models lead to the final design of the energy grid systems for all the application cases and scenarios. With simulations conflicting design choices can be weighted. This can be system functions, component size in weight/power, etc. The results used within the JOULES project is the GWP. The simulations determine the GWP for the operational phase.

Assessment

For the assessment the results of the simulation models are transferred to the LCPA tool. This required an interface file between the simulation and LCPA tool. During a workshop the required parameters are determined to enable this data transfer.

Next to the simulation results more information is required to setup the configuration of the LCPA tool. WG2 partners collaborated with WG3 and WG5 to get all the information in place. Additional information is e.g.: cost price, well to tank data, materials, etc. With all this information the total life cycle performance assessment can be calculated. For the WG5 partners all this information is consolidated into six KPI's.

Figure 10 shows the final result for a single application case as example. From this figure the impact of the design choices becomes clear in a glance. The designer can evaluate the impact on each KPI and make the right compromise for his application. For the JOULES project the GPW is used as reference to the initial project goals.

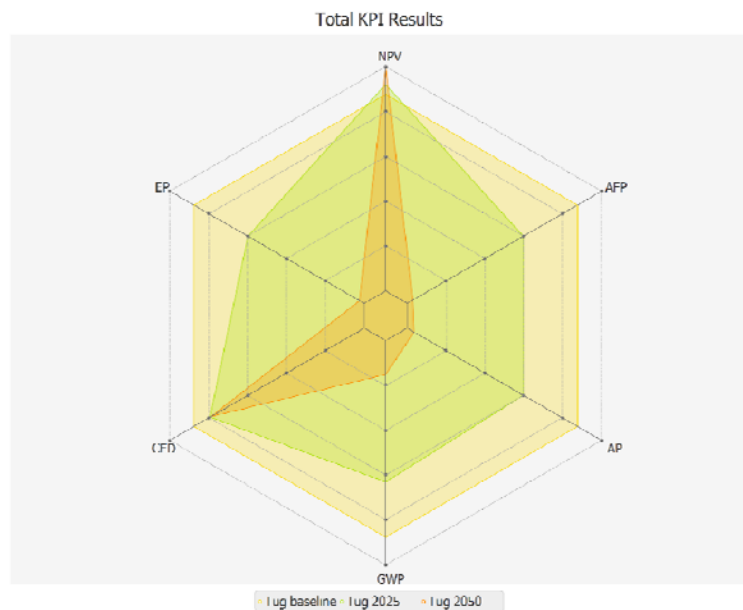


Figure 10: Results of the LCPA consolidated into six KPI's

Results

The direct JOULES project results are 22 new ship designs with a GWP reduction on the short and long term. These designs are developed with a holistic approach which enables the partners to come up with much more innovative concepts in the near future. This is a great advantage since the demand for zero emission ships is increasing, but is still very challenging.

Novel technologies are explored by the European marine industry and experiences are shared. This will lead to a shorter uptake to the market and better integration into ships. As a result the technologies will perform as expected in real life and will be accepted by the market.

Figure 11 shows the final results of the application case for the advanced and next generation designs. It also indicates the impact of the technologies applied for the various ship types. Overall the results fulfill the project targets. This is a big step for the European marine industry to be prepared for the challenging future.

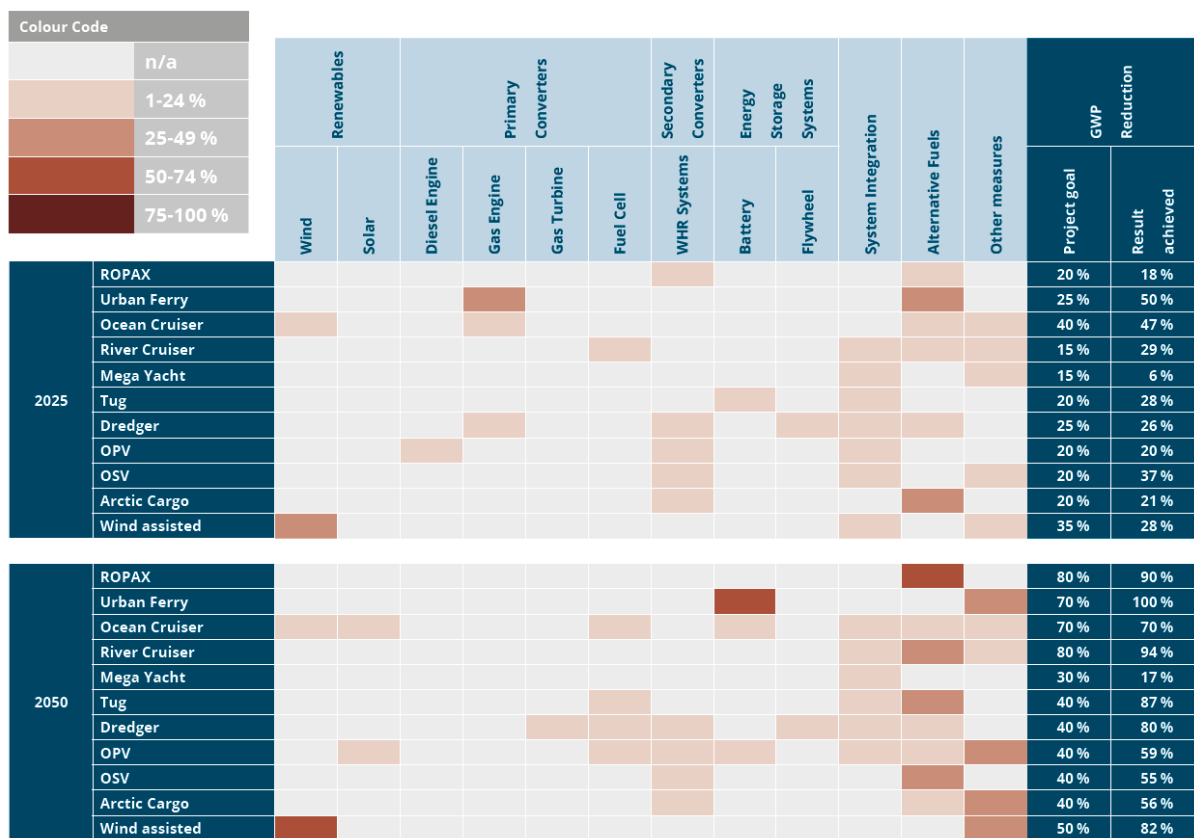


Figure 11: High level results of the advanced and next generation design

4.1.3.5 WG 6

In JOULES three demonstrators were built for measurement campaigns.

The objective of the demonstrators was to prove the modelling work and the results from the components and the application cases.

A state of the art- variant of component, vessel area or technical system of the selected demonstrator cases mark the basis on which the targets of the project were proven. Furthermore a close to reality operational profile was used to validate the new benchmark for a mid- and long term time frame. The demonstrators act accordingly to the design approach related to the research of WG 3 and WG 5.

The three demonstrators represent the bandwidth of the project.

They represent **three technical fields**: the *production* of electrical energy by waste heat, *efficient distribution* of electrical energy and the reduction of *consumption* by the optimisation of real service conditions.

They represent **three different approaches**: the *theoretical knowledge in practical use*, the adaption of *existing technology for maritime use* and a *new approach*.

They represent three **different target groups**: ships with a strong focus on electrical or mechanical energy types like *freighters and workboats*, large *passenger ships* where the accommodation area has a strong impact on the energy consumption of a ship, ships with differing loading conditions like *ferries and freighters*.

They represent **three different scales**: installation on a *real ship*, mock up in a *small scale* and mock up in *full scale*.

They represent **the three JOULES scenarios**: applicability until *2050*, availability to *baseline* scenario ships and implementability on new built ships until *2025* and increase the efficiency of the ship's energy system.

4.1.3.5.1 L.E. Cab demonstrator

Approach

The principle idea of the air conditioning system in the L.E. Cab demonstrator is to do all air conditioning in the cabin rather than transport air from a centralised air conditioning system to the cabin.

This reduces the electrical energy effort by reducing the pressure loss.

For this approach it is necessary to have a complete air conditioning system in the cabin rather than a fan coil as it is state of the art. This means an enormous technical effort. The fresh air is sucked from the balcony and transported to the decentralised air conditioning unit.

Nowadays cabins are equipped with an electrical alternating current (AC) system and the ship's electric grid is considered to be the only energy source. The new approach in the electrical system of the cabin is that the electrical grid of the cabin will be based on direct current (DC) technology.

The electrical system is specified to work with the energy supply of the local energy harvesting system, as well as with the ship's power system as a backup to ensure the energy supply at all times.

In order to compensate the additional weight a lightweight design approach with new lightweight materials for the cabin hull were investigated.

Results

The electrical consumption for air conditioning could be reduced by 70% compared to usual systems.

The decentralised air conditioning system also reduces the installation effort as fresh air ducts are not required.

The electrical consumption for other consumers in the cabin could be reduced by 70%.

On days with good weather the photovoltaic system is feasible to supply the cabin in near future. The energy storage and energy management system is able to store the energy during the day and to supply it during the night after ten years of aging.

Through the use of a new lightweight material for the cabin hull, the overall weight of the cabin could be reduced. Both the weight of the cabin walls and the weight of the cabin ceiling could be reduced by 30-35 %. This more than compensates the additional weight.

4.1.3.5.2 Marine ORC demonstrator

Approach

Waste Heat Recovery (WHR) systems aim at reclaiming wasted thermal energy and converting it to mechanical power following the thermodynamic transitions of the Rankine cycle. The working fluid can be either water/steam, or an organic medium (R134a, R245fa, etc.). Unlike steam, the organic Rankine cycle (ORC) can successfully reclaim waste heat from low temperature heat sources at the order of 90oC, such as the exhaust gas stream of small auxiliary engines, or the jacket water coolant or lubricating oil networks found on-board ships.

Despite the technology readiness of ORC systems, marine references are still limited. The JOULES Marine ORC demonstrator measures and quantifies the actual of a prototype marinised ORC unit and employ advanced simulation and lifecycle assessment tools to analyse the technology operation and estimate life-cycle impact. The ORC unit was designed for on-board waste heat recovery from the cooling water network of a ship's main engine. Due to the experimental nature of the ORC unit, the system was equipped with measuring devices that provide the advantage of extensive performance monitoring.

The Demonstrator performed extensive testing of the operation of the marinized unit and analysed its performance and operability at various conditions. The data acquired during the unit testing were used to calibrate and verify advanced simulation models, which were further used to demonstrate the unit's power production capability and energy efficiency for a realistic operational profile of a vessel.

Results

In summary, the partners in this work could exploit the results of the Demonstrator as follows:

From the yard perspective, motivation stems from the need to provide real-life examples of new technology implementation for the shipping market, in order to prove technical feasibility and drive the market towards adopting novel energy efficiency concepts. In this regard, FSG will exploit the Marine ORC demonstrator for integrating novel waste heat recovery technologies like ORC on-board new projected ships, proving that there is strong technical expertise and know-how for moving the technology forefront beyond the spectrum of conventional solutions.

From the class perspective, DNV GL is strongly motivated to holistically explore the impact of novel ship technologies in terms of safety, environmental performance and effectiveness. Driven by the purpose of safeguarding life, property and the environment, DNV GL aims to enable the shipping industry to advance the safety and sustainability of everyday maritime operations. In this regard, it is very important to estimate the environmental, energy efficiency and safety aspects of new technologies, either on case-specific or fleet-level basis.

Moreover, it is expected that the results of the Marine ORC Demonstrator may be disseminated to the industry aiming at the general knowledge increase and sharing.

4.1.3.5.3 O.D.O.T. demonstrator

Approach

The consumption of marine fuel can be reduced in a number of ways, of which the most obvious ones are the reduction of a ship's speed, improvement of the marine engine's efficiency and reduction of the ship's mass. The less evident measures include optimization of a ship's trim. This latter method is poorly explored and rarely used. However, it has a great potential as, unlike other measures, it can be used without loss of competitiveness, with the help of the existing technology and on the existing ships.

An optimized trim is obtained by manipulating the magnitude and tridimensional distribution of a ship's mass. Studies have shown that for the same displacement, a variation in trim can reduce fuel consumption by as much as 7 %. But while it is impractical to change the mass of the existing ships' structures or, out of consideration for profitability, to reduce the mass of the cargo, it is possible to change the mass and distribution of the ship's capacities.

It is obvious that in order to make a decision of such complexity and urgency, the ship operator must rely on software which will take into account most of the above-mentioned factors and instantly propose a loading scenario which reconciles several operational, economic and maritime criteria while permitting the reduction of fuel consumption. Developing such software is the purpose of this project.

Results

Virtual Test

The program has been tested on a virtual ship, modelled after the Armorique, a fast ferry operated by the Brittany Ferries and transporting cars and passengers between the South Coast of the UK and the North of French. Her capacities constitute more than 60% of the total mass aboard the ship. The algorithm was applied to 11 of the 58 tanks.

Real Test onboard

The algorithm was tested aboard the Armorique during one of the ship's regular passages from Roscoff to Plymouth. A typical Roscoff-Plymouth voyage is conducted at the cruising speed of 22-23 knots and takes 5.5 hours. After the beginning of the voyage, the ODOT algorithm was deployed so as to optimize the ship's loading. A number of optimized loading scenarios were calculated out of which one scenario was selected by the Segula's test engineer and the ship's captain, taking into consideration the algorithm's recommendations as well as the solution's practicality, ship's safety and imperative not to reduce the speed.

Following the ballast discharge operation, the observed speed increase was equivalent to a 900 kW of propulsive power reduction (6.7% of the non-optimized power).

Conclusions

The three demonstrators prove that the results of the JOULES project are applicable in reality.

They represent the large bandwidth of technical approaches in the project.

The demonstrators are applicable on different types of ships, have different scales, work on different technical fields and have different technical approaches.

While LE Cab is feasible in the future only, the Marine ORC can be installed on new built ships soon. The ODOT algorithm is suitable for newbuilds or retrofit of existing vessels.

4.1.4 Impact

4.1.4.1 Expected impact

The introduction of simulation technologies in the early design stage for energy grids has been successfully developed in the course of the JOULES. This does now allow partners and in particular shipyards to introduce further added value into the ship design process. It is expected that the methodologies as developed in the JOULES project will be applied even in the contract phase for newbuildings in order to find optimum solutions with respect to overall energy consumption of vessels for the whole life cycle. This will allow ship yards to improve their competitiveness in increasingly complex market situations.

The simulation component database has been proven to be a reasonable platform for the exchange of simulation models in the maritime industry. Various interests from other organisations have been voiced and the further use of the component database is one core exploitable result of the project.

The validation of the potential impact of dedicated technologies by three demonstrators has contributed to a better understanding, how big uncertainties may be when predicting the energy consumption by simulation.

The work carried out by the application cases has identified significant trends (pathways), how the requested reduction of CO₂ emissions by use of dedicated technologies might look like for different ship types. In addition, the necessary uptake of renewable future fuels depending on ship type has to be considered as expected result from the activities of the application cases. Trade-offs have been identified.

The LCPA tool has finally been used to assess the 2025 and 2050 designs as developed by the application cases against the baseline designs. The results achieved are very much depending on ship type, operational profile, use of future alternative fuels (including fuels from renewable energy), technology used and fuel price projections. A particular result is expected by identification of trade-offs between CO₂-emission reduction technologies (and other end-of-the-pipe technologies for reduction of harmful emissions like scrubbers, SCR and particle filters) and the cumulated energy demand. Making these trade-offs transparent will enhance the understanding of the complexity of introducing future technologies and alternative fuels into the maritime industry. Through this holistic approach, the transition of the maritime industry towards more sustainability and finally to a carbon neutral industry will be supported. From an economic point of view the uncertainty of future predictions of price developments of fuels was in focus together with uncertainties for market uptake of technologies. This led to the introduction of sensitivity studies at a later stage of the project.

Based on a. m. findings, political recommendations have been formulated for necessary short term improvements of energy efficiency to comply with the JOULES targets for 2025 emission reduction and for the long-term uptake of alternative/renewable fuels resp. energies to achieve significant CO₂-reductions as requested in the 2050 scenario.

4.1.4.2 Measures to maximise impact

4.1.4.2.1 Main Dissemination activities

From the beginning of the project, dissemination activities followed a strategy which aimed to address certain messages to different target groups. Over the time, more than one hundred dissemination activities and publications performed by the JOULES partners were reported. The following list gives a statistical overview about the distribution per type of activity. Further below, a selection of important dissemination activities is introduced, highlighting the main target groups **bold letters**.

- 61 Project related dissemination activities, comprising 1 Web site/Application, 4 press releases, 43 oral presentations to scientific events, 1 oral presentation to a wider public (radio interview), 3 posters, 4 Organisations of Workshops, 2 Organisations of Conferences, 1 film, 1 exhibition
- 1 Peer reviewed publication
- 12 Papers in Proceedings of a Conference/Workshop
- 2 Article/Section in an edited book or book series
- 28 Theses/Dissertations and
- 1 University Publication/Scientific Monograph

Public project website

The public project website (address: <http://www.joules-project.eu>, see Figure 12) was established early in the project and has been updated continuously. The website will remain online after the termination of JOULES. It serves as a first entry point for **any interested person** to obtain information about the project. The main parts of the website are:

- Several sections introducing the project in terms of its scope, scientific/technical approach, timeline (project phases), and results
- A news section on a prominent place of the website which calls attention to imminent project events
- A download section on which relevant documents (general information, technical and scientific publications, public Deliverables or public summaries, and documents related to the final conference) are made available to the public

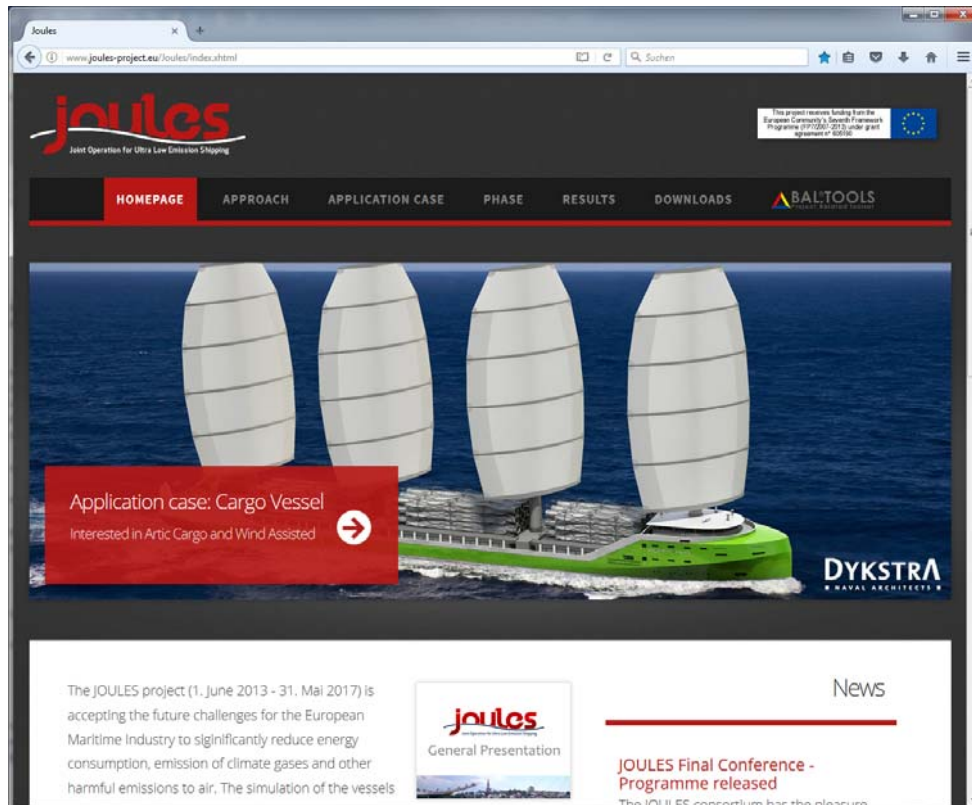


Figure 12: JOULES website home page

EMSHIP

The “EMSHIP week” corresponds to a yearly event performed as part of the European ERASMUS MUNDUS Master in advanced ship and offshore design (EMSHIP) where the **students** of the program share their work and experiences with the rest of the EMSHIP community, as well as academics and industrials related to the marine sector. JOULES made use of the opportunity to organise lectures and discussions about emission reduction technologies, the scientific work done in JOULES, application cases etc. The project achieved a good awareness level of the project among the next generation naval architects and useful feedback. Two EMSHIP events were visited by JOULES:

- EMSHIP week 2015, Nantes (France)
- EMSHIP week 2016, Istanbul (Turkey)

Project brochures

Two JOULES brochures were prepared with the aim to give the **broad public** insight to the project and its achievements. Digital copies are available for download on the project website. Copies of the cover pages are displayed on Figure 13 and Figure 14.

- The first brochure, *Emission reduction technologies* (Link: <http://www.ioules-project.eu/Joules/download?onLQP60yhec%3D=>), gives a general explanation of the project, with a focus on introducing the emission reduction technologies covered.
- The final brochure, *Results from the JOULES project* (Link: <http://www.ioules-project.eu/Joules/download?xj8qSYt6OPo%3D=>), sums up the overall results of the JOULES Project as well as possible ways to exploit the results.



Figure 13: First brochure-cover page

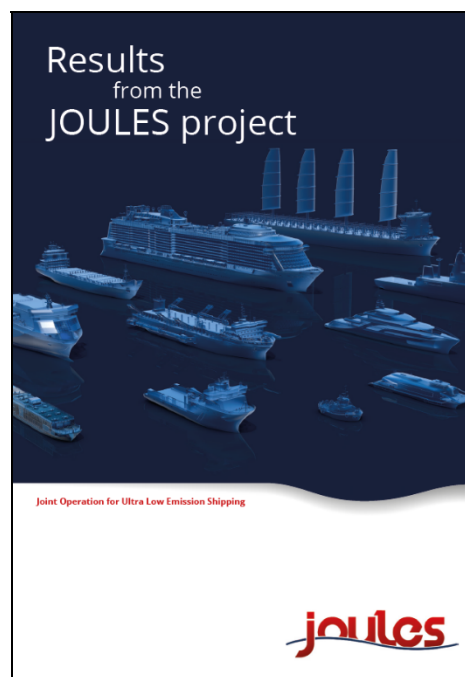


Figure 14: Final brochure-cover page

Participation in conferences

With appearances on a variety of international conferences and other events which cannot be listed here, JOULES partners informed the **professional world** about the approach and the results of the projects. Two of the most prominent events shall be mentioned here:

- ICCAS (International Conference on Computer Applications in Shipbuilding) 2015, Bremen (Germany). By giving as many as five presentations, including a keynote, JOULES took the opportunity to convey a comprehensive overview to representatives from industry and academia. The topics presented were:
 1. Joint Operation for Ultra Low Emission Shipping (Flensburger Schiffbau-Gesellschaft)
 2. Challenges of equipment supplier modelling for the JOULES project (Rolls-Royce plc)
 3. The FMI Standard for Model Exchange and Implementation of a Quality Assurance Pro-cess in a Joint Research Project (Hamburg University of Technology)
 4. Urban Ferries; Combining Technologies and Operational Profiles (DAMEN)
 5. Life Cycle Performance Assessment – method and tool for decision makers (BALance Technology Consulting GmbH)
- TRA (Transport Research Arena) 2016, Warsaw (Poland). Dedicated to the theme 'MOVING FORWARD Innovative Solutions for Tomorrow's Mobility', TRA 2016 contributed to innovation in sustainable mobility for Europe, by bringing together all the stakeholders of every transport mode (researchers, practitioners, designers, constructors, operators, administrators, policy makers etc.). The JOULES Coordinator presented a paper dealing with the project's approach, entitled *A Holistic Approach for Energy Flow Simulations in Early Design*, and a summarising poster.

Audio-visual material

Numerous dedicated publications in print media were given during the project, giving either a general overview on the project or detailed insight into selected subjects. However, at the end of JOULES, the need was obvious to convey the entirety of the projects' achievements and their relevance to the **broad public** in an understandable and digestible way. To that end, audio-visual media are more suitable than print media. Therefore, two dedicated dissemination measures took place shortly before the project termination:

- The JOULES consortium teamed up to produce a project film. Its arc of suspense begins with the inevitable societal challenges connected with climate change and the need to reduce emissions. Then, the general available technical opportunities for emission reduction in shipping were mentioned, followed by the project's approach including assessment methodologies and simulation models. The application cases were introduced briefly and a more detailed explanation of each demo case was given. The film ended with a clear statement: The future scenarios covered in JOULES have shown that shipping is capable to cope with the agreed emission reduction goals for 2025 and 2050 from a technology point of view. The film can be viewed on Youtube (<https://youtu.be/Uch6tL-lKyM>).
- NDR 90.3, a radio station well known in Northern Germany's coast region, broadcasted a radio programme on shipping and environment on May 25th and 29th, 2017. The broadcast was entitled *Von Dreckschleudern und Ökoschiffen*; it was issued as an episode of the regular show *Hamburger Hafenkonzert*. Next to a variety of contributions on shipping and environment, it included interviews with the JOULES Coordinator and the Project Officer. A podcast containing the complete episode can be found on the public domain (http://www.ndr.de/903/sendungen/hamburger_hafenkonzert/Das-Hamburger-Hafenkonzert-Von-Dreckschleudern-und-Oekoschiffen.audio325546.html).

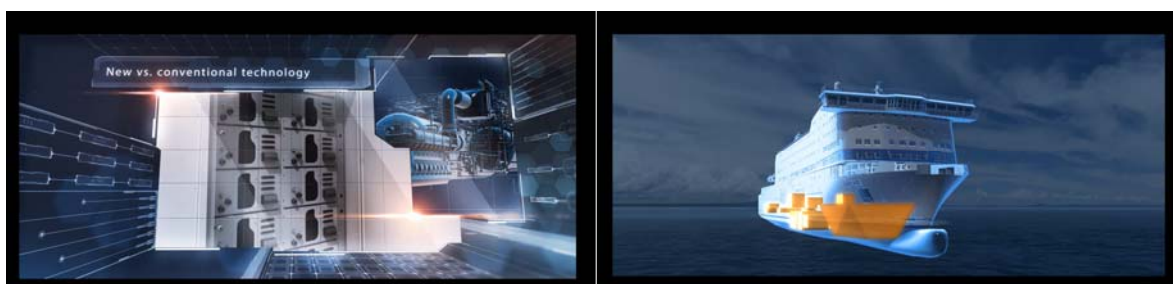


Figure 15: Project Movie- Impressions

External Advisory Group

To establish and maintain a close contact with end users of the technologies investigated in JOULES (i.e. **ship operators**), an external Advisory Group (EAG) was established in Period 1 by the project coordinator (FSG). For information on goals, organisation and work of the EAG please refer to the JOULES Deliverable D13.6 *Report of the Set-Up of the Project Advisory Group*. The EAG convened several times during JOULES. FSG and other partners gave detailed information about the progress of the project. Intermediate results and the way ahead were discussed between EAG members and JOULES partners. Information about the work of the EAG and its out-comes can be found in Deliverable D13.7 *Final Report about Interactions with the Advisory Group*.

Final JOULES project conference

The final conference of the JOULES Project was widely used by stakeholders from **industry, research, NGOs and policy makers** as an opportunity to get first-hand information about the project's outcomes and to discuss possible ways towards their implementation interactively. The conference was held in Hamburg, Germany, on 17 May 2017 under the title *Towards zero emission shipping – Simulating and assessing energy grid for Europe's next generation of ships*. The

conference programme is depicted below. Copies of the presentations, given by several invited keynote speakers as well as members of the project consortium, can be downloaded from the project website.



Figure 16: Conference Program-cover page

Conference Programme			
JOULES Final Conference, 17 May 2017 Hamburg, Historical Warehouse Floor (HafenCity District)			
08:15 – 09:00	Registration, Coffee and Refreshments	12:15 – 13:25	Lunch & Coffee
09:00 – 09:10	Opening, Conference Agenda and Welcome Address Heinrich Klingenberg (Conference Moderator), Managing Director, hySOLUTIONS GmbH Peter Crawley, JOULES EU-Project Officer, European Commission	13:25 – 13:30	Keynote – JOULES Impact from Shipyards' Point of View Mario Dogliani, Technical Director, Sea Europe
09:10 – 09:30	Keynote Speeches ■ The Paris Agreement: A societies GHG-emission budget: Prof. Olav Hohmeyer, Head of Department of Energy and Environmental Management, Europe-University Flensburg ■ Expectations from the ship owners: Jens Kohlmann, Vice President Innovation & Projects, Carnival Maritime, Member of the JOULES Advisory Group	13:30 – 13:55	A Case Study regarding Uncertainty Propagation in JOULES Ship Energy Grid Simulations and LCPA (Life Cycle Performance Assessment) Calculations Arthur Vrijdag, Assistant Professor, Delft University of Technology, Erik-Jan Boonen, Research Engineer, DAMEN Shipyards Group, Markus Lehne, Managing Partner, BALance Technology Consulting
09:30 – 09:55	Objectives and Technical Approach Rolf Nagel, JOULES Project Manager, Flensburger Schiffbau-Gesellschaft mbh & Co. KG	13:55 – 15:05	JOULES Demonstrators ■ Marine ORC (Organic Rankine Cycle) Demonstrator: Alexandros Zymaris, Research Engineer, DNV GL Maritime R&D and Advisory ■ Low Energy Cabin: Kurt Sommer, Research & Development, MEYER WERFT GmbH & Co. KG ■ Operational Displacement Optimisation Tool: Dominique Pons, R&D Project Manager, STX France
09:55 – 10:20	Emission and Operating Expenses Reduction Potential by Optimised Engine and SCR (Selective Catalytic Reduction) Combination Erik Seidel, System Engineer, Emission & Gas Technologies, MAN Diesel & Turbo SE, Rolf Nagel, JOULES Project Manager, Flensburger Schiffbau-Gesellschaft mbh & Co. KG	15:05 – 15:35	Coffee Break
10:20 – 10:50	Coffee Break	15:35 – 15:40	Keynote – JOULES Impact from NGOs Point of View Faig Abbasov, Aviation and Shipping Officer, Transport & Environment
10:50 – 10:55	Keynote – JOULES Impact from Technology Providers' Point of View Steve Mountain, Key Technology Owner – Electrical Systems, Rolls-Royce Marine	15:40 – 16:00	Summary of Results and Political Recommendations Rolf Nagel, JOULES Project Manager, Flensburger Schiffbau-Gesellschaft mbh & Co. KG
10:55 – 11:20	University Knowledge Impact for and beyond the JOULES Project Klaas Visser, Assistant Professor, Delft University of Technology, Erik-Jan Boonen, Research Engineer, DAMEN Shipyards Group, Rick Lotman, Manager R&D, Royal IHC	16:00 – 16:55	Panel Discussion Prof. Olav Hohmeyer, Head of Department of Energy and Environmental Management, Europe-University Flensburg Jens Kohlmann, Vice President Innovation & Projects, Carnival Maritime, Member of the JOULES Advisory Group Steve Mountain, Key Technology Owner – Electrical Systems, Rolls-Royce Marine Mario Dogliani, Technical Director, Sea Europe Faig Abbasov, Aviation and Shipping Officer, Transport & Environment Dr. Heike Deggim, Senior Deputy Director, Marine Environment Division, International Maritime Organization Peter Crawley, JOULES EU-Project Officer, European Commission Rolf Nagel, JOULES Project Manager, Flensburger Schiffbau-Gesellschaft mbh & Co. KG
11:20 – 11:45	Measurement, Modelling and Fuel Choice for HTPEM (High Temperature Polymeric Electrolyte Membrane) Fuel Cells Christoph Thiem, Scientific Associate, Hamburg University of Technology, Kurt Sommer, Research & Development, MEYER WERFT GmbH & Co. KG	17:00	Closing of the Conference followed by a "Get Together" – Reception with Flying Buffet
11:45 – 12:15	From Idea to Design by Means of Simulation Erik-Jan Boonen, Research Engineer, DAMEN Shipyards Group, Sandor Ivancsics, Research Engineer, DAMEN Shipyards Group, Frederick Vandepitte, Development Engineer, DAMEN Shipyards Group		

Figure 17: Conference Program

4.1.4.2.2 Exploitation of results

Exploitation strategy

Similar to the dissemination activities of the project, the exploitation of results will follow a dedicated strategy. A schematic representation of the JOULES exploitation strategy – the exploitation pyramid – is depicted in Figure 18. The meaning of the several storeys of the pyramid is as follows:

- The fundament of the pyramid consists of the results of the project – without results, no exploitation can take place. The caption in the pyramid is a high-level summary of the results. Each of these high level results represents a set of specific exploitable results (i. e. exploitable Foregrounds – eFG) which the corresponding responsible partners have described in detail in Deliverable D13.5.
- The four central stories of the pyramid are introducing the types of measures foreseen within the exploitation strategy. The partners' detailed exploitation plans related to the eFGs are also elaborated in D13.5. In principle, each type of exploitation measures is directed towards one or more of the target groups in the maritime community that were addressed in the initial dissemination strategy. The particular types of measures, starting from the bottom, are:
 - 'Targeting at decision making bodies, convince decision makers in companies': Measures in this field aim at representatives in the target groups 'ship building community' and 'ship owners and operators' to really apply emission reduction technologies; in addition, the measures are aiming at implementing political recommendations (target groups 'rule makers', 'policy makers', 'research administration', see also explanations on '*Measures to maximise the exploitation of results*' further below in this section) to improve the frame conditions for such application. More information can be found in the public Deliverable D21.1.
 - 'Extend community – Provide best practise, share results, create awareness, offer tools and services': To make zero emission shipping happen, the results of the project must be known and applied by all members of the maritime community in Europe, but not only the JOULES partners. The measures in this storey are aiming at a wide cooperation with all target groups mentioned in the dissemination strategy.
 - 'Maintain Competitiveness (technical superior, economic viable)': The measures in this storey are related to creating business out of the eFGs. Hence, the 'target group' consists of the project partners themselves. Most of the partners individual exploitation plans in D13.5 are related to this storey.
 - 'Continue co-operation': Existing project results which represent collections of knowledge (e.g. fuel table, component data base) are highly valuable today, but will be outdated quickly. A set of exploitation measures is aiming at making the results sustainable by keeping them updated continuously, e.g. by making the component database available in HOLISHIP as a starting point. The target group is the entirety of members of the JOULES consortium.

- Finally, the top floor of the pyramid represents the mission of the project, which is a societal one, namely to contribute to climate protection by zero emission shipping. All the results and all the exploitation measures in the lower floors are supporting this overarching mission.

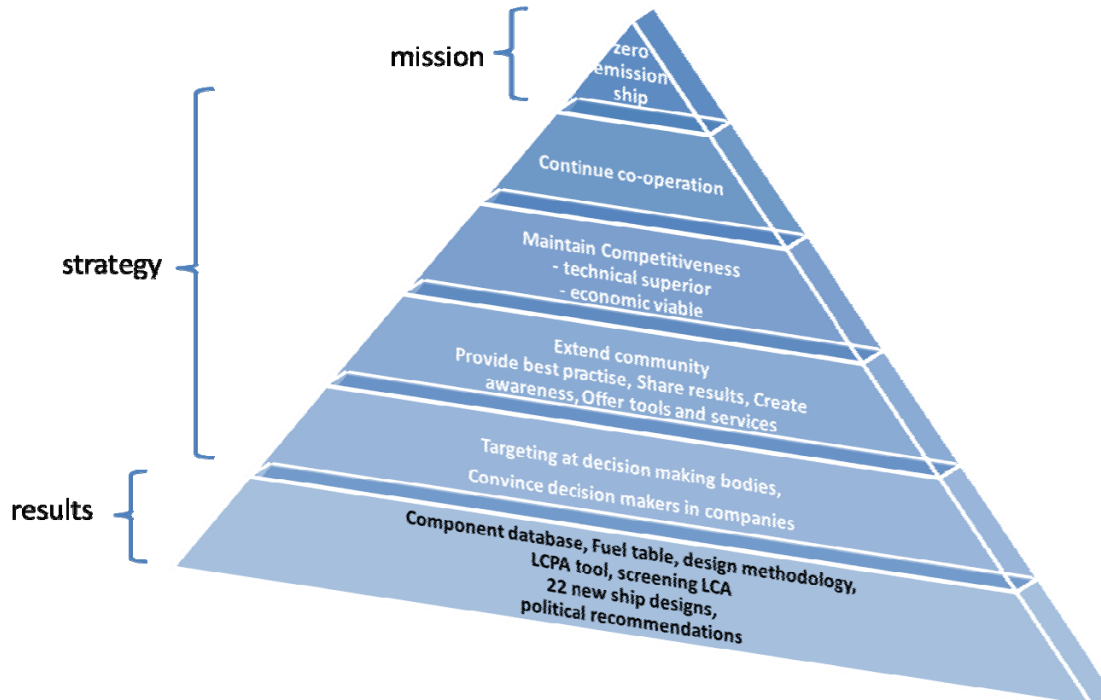


Figure 18: Joules strategic Approach towards Exploitation

Measures to maximise the exploitation of results

In the public Deliverable D21.1 *Political Recommendations*, suggestions have been elaborated on how maximum exploitation of the JOULES results can be encouraged. In section 7 *Final Conclusions and Political Recommendations*, special attention was given on how such measures can support the implementation of the ‘Paris Agreement’²:

The societal challenge to reduce GHG-emission in the future acc. to the Paris Agreement will need substantial contributions from the maritime industry. On the other hand, expected increase of global GDP with associated growth in shipping fleet makes it difficult to project required reduction. However, business as usual will increase the absolute GHG-emissions and share of total emissions dramatically over time.

The JOULES project has offered possible technical solutions and managed to model ships that comply with the objectives as outlined for the project. However, it has not been proven yet that such future ultra-low emission ships can be built. Really developing and building these innovative ships will cost a lot of time and money and there will still be risks that technologies might not be in place as required.

The following Figure 19 illustrates a possible framework for further **long term** political support to reduce GHG-emissions in practice. It can be stated that actual baseline designs

² Agreement within the United Nations Framework Convention on Climate Change (UNFCCC) dealing with greenhouse gases emissions mitigation, adaptation and finance starting in the year 2020, negotiated by representatives of 195 countries at the 21st Conference of the Parties of the UNFCCC in Paris.

using fossil fuels are impacting climate change which coincides with high external costs which are currently paid by the society. From a technology point of view, various developments are underway being able to substantially reduce all kinds of emissions from ship (and in particular GHG-emissions) and have been theoretically applied in the 11 application cases within the JOULES project. Along with intensified R&D to make these technologies mature for integration into new built ships, the pathway towards market uptake should be supported by political action. Efficiency of future technologies (e. g. fuel cells, wind assist, energy recovery systems, energy storage technologies) as well as longevity must be substantially enhanced. Space and weight requirements are pertinent in shipbuilding and ongoing improvements are needed. At the same time the production costs for such future technology must be reduced significantly. The existing technology gaps require considerably high R&D efforts in the future.

In parallel there is a compelling need for sustainable upstream processes and land infrastructure network to be in place for the introduction of alternative / sustainable fuels in the maritime industry. The costs at which such fuels can be produced in the future are of utmost importance for a successful transition.

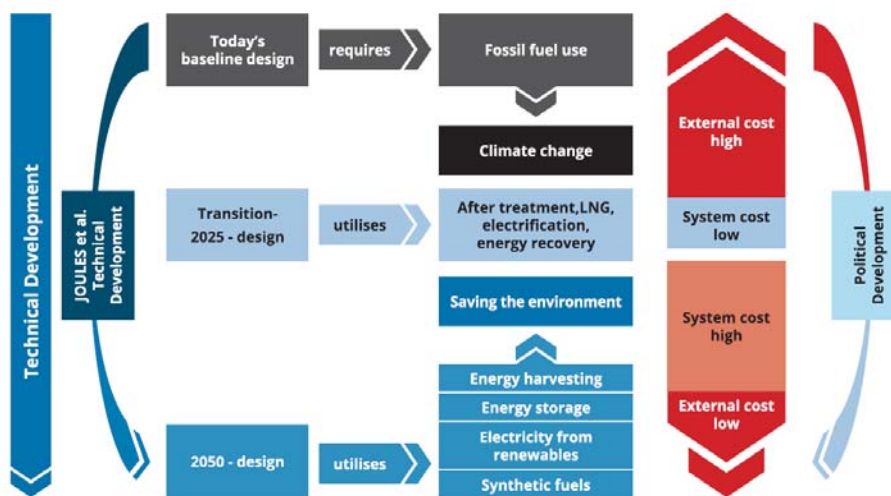


Figure 19: Political Development to support transition to ultra low emission shipping

4.1.5 Relevant contact details

4.1.5.1 Coordinator contact



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