Zero waste Heat vessel towards relevant Energy savings also thanks to IT technologies

ZHENIT_List of confidential deliverables summaries

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Clean and competitive solutions for all transport modes - Innovative on-board energy saving solutions

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Document History

Project Acronym	ZHENIT
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List of Organizations

Participant Name		Short Name	Country	Logo
1	RINA Consulting Spa	RINA-C	Italy	
1.1	RINA Services Spa	RINA-S	Italy	
2	Ethnicon metsovion polytechnion	NTUA	Greece	
3	Danelec	KYMA	Norway	
4	Fundacion tecnalia research & innovation	TECNALIA	Spain	
4.1	Universidad del pais vasco/ euskal herriko unibertsitatea	UPV/EHU	Spain	
5	Attica Group	ANEK	Greece	
6	Consiglio nazionale delle ricerche	CNR	Italy	
6.1	Consorzio di ricerca per l'innovazione tecnologica, sicilia trasporti navali, commerciali e da diporto scarl	NAVTEC	Italy	
7	Sorption technologies gmbh	SORTECH	Germany	
7.1	Sorption technologies srl	SORTIT	Italy	
8	Bound 4 blue sl	B4B	Spain	
9	Encontech bv	ECT	Netherlands	
10	Gruppo sigla srl	SIGLA	Italy	
11	The University of Birmingham	UoB	United kingdom	

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List of confidential deliverables

WP No	Del No	Deliverable Name	Lead Beneficiary	Type
WP 1	D1.4	ZHENIT Reference vessels overall energy/thermal balance and energy assessment of the waste heat on board	RINA-C	R
WP 1	D1.5	Thermoeconomic optimization for WH2R/RES/TES integration on board of ZHENIT reference vessels and guidelines for optimal design of ZHENIT solutions	UoB	R
WP 2	D2.1	Development and detailed design of the sorption desalination and cooling unit	CNR	R
WP 2	D2.2	Development and detailed design of the Isobaric Engine	ECT	R
WP 2	D2.3	Optimised design of the ORC-ejector heat pump prototype	NTUA	R
WP 2	D2.4	Experimental validation under lab-controlled conditions of the developed WH valorisation technologies	TECNALIA	R
WP 3	D3.1	Requirements and specifications of ZHENIT technologies for thermal management and control systems implementation	CNR	R
WP 3	D3.2	On-Board monitoring platform integrated with ZHENIT needs	SIGLA	R
WP 3	D3.3	Development and testing of a TES system	UoB	R
WP 3	D3.4	CFD models of eSAIL influence on the overall vessel efficiency	B4B	R
WP 3	D3.5	Integrated numerical platform for dynamic simulations and numerical results	NTUA	R
WP 3	D3.6	Control platform for the lab and on-board tests	SIGLA	R
WP 3	D3.7	Enhancement and optimization of the control platform	SIGLA	R

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WP 4	D4.2	Laboratory test site completely prepared for the integration of prototypes	TECNALIA	R
WP 4	D4.3	Pilot vessel completely prepared for the integration of the demo technologies	RINA-S	R
WP 4	D4.4	Report on the operation, monitoring and data analysis of the integrated prototypes at TECNALIA lab	TECNALIA	R
WP 4	D4.5	Report on the operation, monitoring and data analysis of the pilot vessel WH system	RINA-C	R
WP 5	D5.4	Envirionomics assessment of ZHENIT Solutions: CBA, LCA and LCC	RINA-C	R
WP 5	D5.7	TRL9 Roadmap including Social and regulatory assessment of ZHENIT solutions	RINA-C	R
WP 5	D5.8	Market assessment of ZHENIT Solutions identifying preliminary business models	RINA-C	R
WP 6	D6.3	ZHENIT Preliminary Dissemination and Communication Plan	RINA-C	R
WP 6	D6.4	ZHENIT Dissemination and Communication Plan - Update	RINA-C	R
WP 6	D6.8	First Exploitation Report and KERs identification	RINA-C	R
WP 6	D6.9	ZHENIT Dissemination and Communication Plan - Update 2	RINA-C	R
WP 6	D6.11	Final Exploitation Report and IPR management guidelines	RINA-C	R
WP 7	D7.1	Executive Action Plan	RINA-C	R
WP 7	D7.2	Data Management Plan	RINA-C	R
WP 7	D7.3	Ethics Self Assessment	RINA-C	R
WP 7	D7.4	ZHENIT risk matrix and project objectives/impacts KPI Panel for project reporting/tracking	RINA-C	R
WP 7	D7.5	Data Management Plan - final review	RINA-C	R

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D1.4 ZHENIT Reference vessels overall energy/thermal balance and energy assessment of the waste heat on board (RINA-C)

The ZHENIT Project aims to promote Waste Heat Recovery (WHR) as key and solutions to achieve 2030 International Maritime Organisation and European Union targets for shipping sector decarbonization. The targets of the project are new technologies development, on-board validation, a regulatory framework analysis and a replication roadmap at regulatory and economic level. There are several solutions for recovery of waste heat with different temperatures ranges of application, technology stages, saving potential and efficiencies. The main technologies investigated in the context of the ZHENIT project are: organic Rankine cycles, thermal energy storage, sorption desalination and refrigeration, isobaric expansion engines and wind propulsion. There are other technologies either already implemented or with clear potential for marine engine waste heat recovery such as turbocompounding, steam Rankine cycles, thermoelectric generation, absorption refrigeration, organic flash cycles and Kalina cycles. The present document constitutes the Deliverable D1.4 of the ZHENIT project, focused on “reference vessels overall energy/thermal balance and energy assessment of the waste heat onboard” and is produced within Task 1.1, “energy assessment of waste heat on board of different vessels”. This task's objectives include quantifying the WH streams on board various vessels, capturing the temperature range at which WH is available, and detecting the WH's dynamic behavior and connecting it to the ship's scheduled operation (such as a cruise, harbor stay, or manoeuvre, for example). By quantifying WH resources across marine sectors and identifying the most pertinent sources of WH on ships to be valorized through the ZHENIT technologies created in WP2, this will support replication in WP5. The ANEK Olympic Champion and La Naumon, the project's two demo vessels, are used to conduct the energy assessment in this deliverable. Based on the consortium members' prior expertise, further data are then gathered for other vessels that fall into various categories.

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D1.5 Thermoeconomic optimization for WH2R/RES/TES integration on board of ZHENIT reference vessels and guidelines for optimal design of ZHENIT solutions (UoB)

This report delivers the techno-economic analysis (TCA) planned in task 1.5 of the ZHENIT project work plan. The report provides the modelling approaches, assumptions, details of the individual case studies (individual vessel types), comprehensive results and discussion of the role, value, and benefits of the ZHENIT technologies in recovering, converting, and storing waste heat (HW). Emphasis is put on the benefits at the whole-vessel level of both the individual ZHENIT technologies (Organic Rankine Cycle (ORC), Sorption, isobaric expansion engine (IEE), and Thermal Energy Storage) as well as their combined use. The individual case studies considered extensively cover both the shipping sector (task 1.5.1) as well as the passenger sector (task 1.5.2). Specifically, the TCA comprehend cruise vessel (passenger sector), cargo vessel (shipping sector) and a generalised vessel in order to extend the results and implications of ZHENIT solutions to a broader range of cases. The results and analysis for each case study comprehensively assess the environmental and economic implications of ZHENIT technologies for onboard energy systems. Specific key performance indicators (KPIs) are evaluated and discussed: CapEx, OpEx, fuel consumption and CO2 emissions, to ascertain both the economic viability as well as the environmental impact. Based on the TCA analysis, a layout for each vessel type is proposed; the layouts inform about what ZHENIT technologies (in isolation or combination) are better suited for each vessel type (in passenger and shipping sectors), providing general guidelines for the adoption of such technological solutions also in the instances of vessels not directly considered in the present report. Therefore, the results support the replication analysis and pathways to impact that will be comprehensively studied in WP5. In the ZHENIT study, key indicators showed that both cruise and cargo vessels achieved significant improvements in energy efficiency. Cruise vessels, with their varied journey profiles—marked by changes in speed, multiple stops, and variations in WH and demand—achieved about 13.5% efficiency improvement. This variability led to the use of the dynamic MILP method for their analysis. In contrast, cargo vessels, with their more predictable journeys, showed an 11.5% rise in efficiency when evaluated using the single-point TCA approach. Across the board, both vessel types exhibited consistent fuel savings of about 7.5%. Sensitivity analysis suggested that under certain conditions, like reduced equipment costs or tweaks in temperature limits, this efficiency might increase to 14.5%. Economically, the ZHENIT approach promises a payback period of 5 to 8 years, better than typical payback period in the literature. Additionally, the estimated Net Present Value (NPV) highlight

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the long-term financial potential of the ZHENIT approach, representing 4% to 20% of a vessel's total value. In conclusion, ZHENIT offers a solid approach for ship operators looking to improve efficiency, reduce carbon emissions, and enhance profitability in the face of rising operational costs. The report also includes general guidelines also reflect factors that should be removed to make ZHENIT solutions more attractive. The TCA presented in this deliverable is supported by data sourced from D1.1 (Task 1.2 Catalogue of WHR technologies for maritime applications) and D1.4 (from T1.1 Energy Assessment of WH on board of different vessels). The data includes a comprehensive literature review covering technology applications, configuration specifications, boundary conditions, and vessel audit details. The conclusions backed by discussions and detailed analysis in this report set the foundation for subsequent phases of the ZHENIT project, specifically WP5 (Technologies Evaluation and Impact Assessment Towards Replication).

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D2.1 Development and detailed design of the sorption desalination and cooling unit (CNR)

The performed investigation during first 18 months of ZHENIT project, in the framework of Task 2.1 activities, provided the necessary information to define the preliminary design of the adsorption desalination and cooling prototypes for the next steps of the project. Specifically, the Task 2.1 activities were divided in three sub-sections:

- System architecture design and modelling;
- Adsorbent materials optimization;
- First complete preliminary design of the prototypes;

Regarding the system architecture and modelling, it started from the existing adsorption cooling and desalination architecture units, with a deep literature analysis. Based on this investigation and on the patented innovative configuration by SORP, a numerical model of the system was implemented in Dymola/Modelia environment. The implementation was also exploiting previous experiences and knowledge acquired by CNR in other R&D projects. The numerical model of the innovative configuration was tested to validate the reliability of the simulation and the proper operation. In the next steps, it will be firstly validated against the first experimental outcomes and then used to support WP3 and WP4 investigation, especially providing inputs to the overall ZHENIT system model and to refine the control logic of the prototypes during the validation campaign both in the lab and on-board of the demo vessel. The investigation at materials level started from the identification of commercial and on-purpose developed materials, with high water sorption ability and promising features. A deep and detailed experimental campaign was performed to identify morphological and structural features as well as to define the most effective solutions from thermodynamic and kinetic point of view. The thermodynamic characterization allowed to identify the composite sorbents (embedding a hygroscopic salt inside a matrix) as the most effective ones. Specifically, when cooling is the primary need, the composite sorbents show the highest thermodynamic performance, while, under typical desalination conditions, also the standard adsorbents, like microporous silica gel, achieve competitive performance. The most promising materials were then selected for the kinetic characterization, which demonstrated the crucial ole of this parameter in the final selection. Indeed, when the sorption kinetic comes into play, it is highlighted how the pure sorbents become even more competitive against composite sorbents. This is

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mostly due to the slow reaction kinetic of the salt hydration compared to the pure physical adsorption inside the pores of the adsorbent material. For this reason, the silica gel Siogel, thanks to its wide availability, low cost and low corrosiveness potential was selected for the demonstration phase of the project. The last phase was dedicated to the preliminary design of the prototypes for the next stages of the project. In particular, the two prototypes were differentiated in order to cope with the requirements in the testing lab and on-board of the demo vessel. The adsorbent material and components were identified and the P&IDs reporting all the connections and the planned sensors were defined. These &IDs will be further refined in the next months, also in collaboration with WP4, to align perfectly the prototypes' architecture with the validation facilities. Moreover, the specifications of each sensor to be installed will be further refined and the amount of adsorbent material to be embedded inside the prototypes will be selected according to the cooling and desalination capacities to be achieved in both validation campaigns. Particularly, further study will be focused on the system integration on-board, both for marine environmental requirements and for safety aspects which the installation on-board vessels will require. The feasibility of integration will therefore be analyzed and possible modifications or components integration will be studied if required by the marine environment and the vessel safety. After these stages, the final design will be issued and the manufacturing process will start, aiming at finalizing the CNR lab testing campaign by summer 2024 and then moving to the next validation in WP4.

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D2.2 Development and detailed design of the Isobaric Engine (ECT)

ZHENIT project main objective is to promote WHR as key and "ready-to-scale up" solutions to greatly contribute to 2030 IMO/EU decarbonization targets with the aim to validate innovative WHR solutions at various temperature levels, optimizing its integration and performance. One of these WHR technologies considered in the project relates to the development of an isobaric expansion engine prototype. This report relates to D2.2 "Development and detailed design of the isobaric Engine", which is directly related to the activities described in Task 2.2 "Design of Isobaric Expansion Engine" of the project, and specifically to activities performed within the framework of Subtasks 2.2.1 "System modelling", 2.2.2 "Material definition and conceptual design" and 2.2.3 "Detail design of the IE Engine". Isobaric expansion (IE) engine is a quite novel heat-to-mechanical-work conversion technology that presents a promising solution for the recovery and revalorization of low-grade heat. The first part of this report presents a brief introduction to the technology itself, addressing from the historical early references to such systems, its general characteristics, main advantages to finally presenting the different engine's types or configurations. A numerical approach in Engineering Equation Solver software was developed to evaluate the expected performance of this technology considering different working fluids and mixtures over a wide range of operating temperatures and working pressure ratios, and ultimately, for the definition of the most suitable working fluid for the application relevant to the project. The numerical model results were then transposed into a detailed polynomial approach representation of a reference IE Engine, and finally, integrated into a stand-alone model built in Dymola (FMI) to be provided to WP3 and integrated into the ZHENIT solutions dynamic simulation platform.
ZHENIT project main objective is to promote WHR as key and "ready-to-scale up" solutions to greatly contribute to 2030 IMO/EU decarbonization targets with the aim to validate innovative WHR solutions at various temperature levels, optimizing its integration and performance. One of these WHR technologies considered in the project relates to the development of an isobaric expansion engine prototype. This report relates to D2.2 "Development and detailed design of the isobaric Engine", which is directly related to the activities described in Task 2.2 "Design of Isobaric Expansion Engine" of the project, and specifically to activities performed within the framework of Subtasks 2.2.1 "System modelling", 2.2.2 "Material definition and conceptual design" and 2.2.3 "Detail design of the IE Engine". Isobaric expansion (IE) engine is a quite novel heat-to-mechanical-work conversion technology that presents a promising solution for the recovery and revalorization of low-grade heat. The first part of this

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report presents a brief introduction to the technology itself, addressing from the historical early references to such systems, its general characteristics, main advantages to finally presenting the different engine's types or configurations. A numerical approach in Engineering Equation Solver software was developed to evaluate the expected performance of this technology considering different working fluids and mixtures over a wide range of operating temperatures and working pressure ratios, and ultimately, for the definition of the most suitable working fluid for the application relevant to the project. The numerical model results were then transposed into a detailed polynomial approach representation of a reference IE Engine, and finally, integrated into a stand-alone model built in Dymola (FMI) to be provided to WP3 and integrated into the ZHENIT solutions dynamic simulation platform. Then, the definition of the IE Engine conceptual design was performed, which should fulfil the objectives specified within the Description of the Action (DoA): "1) To develop, design and test an isobaric expansion engine for WH-to-mechanical work, to be used to drive fuel compression or other on-board mechanical processes (…) and 2) This system will be able to valorise WH at different temperature ranges T < 100 °C and even as low as 40-50 °C with different efficiencies (…)." Finally, the detailed design of the IE Engine prototype was performed. Production engineering drawings for the manufacturing of the isobaric expander and the refrigerant feed pump were developed. Also, a detailed definition of the main heat exchangers was accomplished, and the preliminary characteristics of the electrical requirements and control strategy were addressed. hen, the definition of the IE Engine conceptual design was performed, which should fulfil the objectives specified within the Description of the Action (DoA): "1) To develop, design and test an isobaric expansion engine for WH-to-mechanical work, to be used to drive fuel compression or other on-board mechanical processes (…) and 2) This system will be able to valorise WH at different temperature ranges T < 100 °C and even as low as 40-50 °C with different efficiencies (…)." Finally, the detailed design of the IE Engine prototype was performed. Production engineering drawings for the manufacturing of the isobaric expander and the refrigerant feed pump were developed Also, a detailed definition of the main heat exchangers was accomplished, and the preliminary characteristics of the electrical requirements and control strategy were addressed.

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D2.3 Optimised design of the ORC-ejector heat pump prototype (NTUA)

The present report corresponds to Deliverable D2.3 «Optimised design of the ORC-ejector heat pump» prototype of the ZHENIT project. It covers part of the activities carried out within Task 2.3 "Conceptual design of advanced ORC integrated with ejector" of Work Package 2 "Modelling and Design WH valorisation solutions at different temperatures". More specifically, the report covers all activities carried out within Subtask 2.3.1 "System modelling", Subtask 2.3.2 "Material definition and conceptual design" and part of the activities carried out in Subtask 2.3.3 "Detailed design of the advanced ORC ejector heat pump system". The two key objectives of the activities reported are the following: 1) Define the best configuration of the ORC-ejector heat pump prototype and 2) Determine its design point, which includes a) the selection of the best refrigerant working fluid to be used in the prototype and b) the definition of its thermodynamic states and mass flow rates in all locations of the system at different operating modes while also considering the mass flow rate and thermodynamic state of hot water, cooling water and chilled water streams used for providing driving heat, cooling down and cooling production at the inlet/outlet of respective heat exchangers. Regarding the first objective, multiple possible configurations of ORC and ejector heat pump systems were considered. Some of them were excluded a priori from final consideration because of their technical/thermodynamic infeasibility or critical setbacks, while the remaining were investigated through numerical models developed in Matlab software. Ultimately, a parallel ORC-parallel EVCC configuration driven by waste heat at high temperature (140 °C) was found to be the best in terms of thermodynamic performance, simplicity, space and weight requirements and cost. This configuration has two main features: the ORC and ejector heat pump are physically integrated, operating with the same working fluid and connected in a parallel configuration. Furthermore, the compressor and ejector of the ejector heat pump are also connected in parallel. The selected working fluid for the system is hydrochlorofluoroolefin R1233zd(E), owing to its safety of use, commercial availability, and environmentally favorable properties. The maximum cycle temperature of the prototype will be 130 °C. Moreover, the deliverable includes results related to the dynamic modelling of the ORC system of the prototype in Dymola software. These simulations were carried out to verify the dynamic response of the prototype under different scenarios. Finally, the prototype includes a P&ID diagram of the prototype.

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D2.4 Experimental validation under lab-controlled conditions of the developed WH valorisation technologies (TECNALIA)

ZHENIT project main objective is to promote WHR as key and "ready-to-scale up" solutions to greatly contribute to 2030 IMO/EU decarbonization targets with the aim to validate innovative WHR solutions at various temperature levels, optimizing its integration and performance. Some of these WHR technologies considered in the project are sorption desalination and cooling unit, isobaric expansion engine and ORC-ejector integrated heat pump. In this report, only information related to sorption desalination and cooling unit, isobaric expansion engine and ORC-ejector integrated heat pump manufacturing and experimental testing is included. Detailed information on the sorption desalination and cooling system design is available in D2.1 "Development and detailed design of the sorption desalination and cooling unit", the Isobaric Expansion Engine (IEE) design in D2.2 "Development and detailed design of the Isobaric Engine" and ORC-ejector design in D2.3 "Optimised design of the ORC-ejector heat pump prototype". The two key objectitives of the activities reported are the following : 1) based on the detailed designs of the prototypes to be manufactured and 2) conduct an experimental validation campaign under lab-scale controlled conditions of each tecnology in order to characterize the systems and provide assurances to WP4 "Validation Campaign". Chapter two of this document provides a detailed description of the steps undertaken in the manufacturing of the sorption desalination and cooling unit, along with the results of the validation campaign. Section three focuses on the manufacturing and validation campaign under lab-conditions of the isobaric expansion engine conducted in TECNALIA´s laboratory. Finally, chapter 4 presents the progress achived in the construction of the ORC integrated with ejector and the results obtained from its validation campaign.

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D3.1 Requirements and specifications of ZHENIT technologies for thermal management and control systems implementation (CNR)

ZHENIT concept is based on a combination of different innovative technologies able to convert waste heat available on-board into electricity, heating, cooling, desalinated water and mechanical energy. During the Task 3.1 activities, summarized in the present deliverable, different possible layout configurations were derived for some example of possible reference vessels. Specifically, the following ZHENIT architectures were defined:

- Generic system: including all the ZHENIT technologies, namely, Organic Rankine Cycel (ORC) with ejector-aided heat pump, thermal energy storage (TES), adsorption cooling and desalination machine (ADS) and isobaric engine (IE). This can be considered the most complete configuration that can be adapted to a large variety of vessels.
- La Naumon-like system: including the ORC, the TES and the ADS (only providing cooling). This system is considered relevant whenever the mission profile of a vessel comprises short to medium sailing phases followed by short to medium docking phases in the harbour.
- Olympic Champions-like system: including ORC and IS. This system is considered relevant whenever the mission profile of a vessel comprises shor sailing phases followed by brief docking phases, e.g. embarking/disembarking passengers like for a ferry.
- Cruise ships-like system: this is conceived in two different architectures, in both cases ORC and TES are integrated, while in one case the ADS is integrated while in the other one the IE. The selection of the most proper one will then depend on the most efficient one depending on the achievable savings, space availability and other technical aspects.

An example of P&ID realized, for the generic system, is represented in the deliverable. It reports all the sensors and actuators needed to properly monitor and control the operation of the ZHENIT system on-board. The full list of sensors and actuators was extracted and organized as input and outputs. According to the information shared by each technology developer, the specific operating modes of each ZHENIT technology were defined as basis to identify the possible operating modes of the overall ZHENIT systems. Specifically, for each system, the possible services to the vessel (e.g. power, heating, cooling generation) were listed and the possible operating modes that can be activated to cope with these requests were defined. Finallly, these operating modes were detailed by identifying, under each

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condition, the actuators that are activated. The developed P&IDs and operating modes will be the basis for the control and monitoring activities to be perfromed in the next tasks of WP3 as well as the full system modelling. At the same time, starting from the WP3 P&IDs, preliminary design of the integration to be performed at TECNALIA lab for the WP4 validation as well as the possible control architecture were drafted, to be further validated in the next phases of the project.

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D3.2 On-Board monitoring platform integrated with ZHENIT needs (SIGLA)

The D3.2 deliverable presents the development of an on-board monitoring platform designed to supervise and manage energy flows associated with waste heat recovery technologies within an integrated system environment. The platform is built upon a layered industrial architecture combining PLC-based control, SCADA supervision, and a user-oriented HMI, ensuring a clear separation between automation logic and supervisory functions. This modular approach enhances scalability, interoperability, and ease of integration across heterogeneous technologies, which are treated as independent functional modules capable of exchanging data through open communication protocols. The system relies on a centralized data aggregation mechanism, where process information from multiple subsystems is collected, processed, and made available for real-time monitoring, historical analysis, and performance evaluation. A key feature of the platform is its multi-control philosophy, allowing different supervisory interfaces to interact with the control layer while ensuring safe and deterministic operation through command arbitration mechanisms. The HMI is designed to provide an intuitive and comprehensive visualization of the plant, supporting both passive monitoring and active control, including device operation, alarm management, and access to detailed trends. In particular, the platform enables high-resolution data logging and visualization, facilitating advanced diagnostics and long-term performance assessment. The implementation of structured command and feedback exchanges between the SCADA and PLC ensures consistency and reliability in system behavior. Additionally, the platform incorporates automated operational sequences based on state-machine logic, as well as configurable cause-and-effect matrices that allow flexible definition of operating scenarios and responses to system conditions. Emergency management functions are integrated to guarantee safe shutdown procedures and controlled system behavior under fault conditions. Overall, the monitoring platform represents a robust and flexible solution supporting efficient energy management and optimization of waste heat recovery processes, in line with the broader objectives of improving system performance and operational sustainability.

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D3.3 Development and testing of a TES system (UoB)

The ZHENIT project aims to identify and assess potential solutions for waste heat recovery on board vessels. This research investigates the use of existing technologies for on-board applications, the development of new technologies, the application of energy management methods, the economic impacts of the technical proposals, and the regulatory framework. Specifically, Work Package 3 addresses the dynamic simulation and control of the thermal processes of vessels, with a focus on integrating thermal energy storage (TES) systems. As outlined in the work plan for Task 3.3, this report provides the detailed design of the TES prototype, evaluates its performance, analyses the main design choices, describes the realisation process, and assesses the costs involved. The deliverable consists of ten sections: the Executive summary, the Introduction, the TES concept, the Key performance indicators (KPIs), the Modelling overview, the PCM selection, the TES prototype esign, the Prototype realisation, the Commissioning tests, and the Conclusions. The introductory part outlines the background on the application of TES systems on board vessels for the optimal exploitation of waste heat and the advantages of its integration with other technologies. The rationale and objectives of the research are defined, and the hypotheses applied and their effects on the achieved results are indicated. Moreover, the facility of the laboratory of Tecnalia is described along with the explanation of the hydraulic system necessary for installing the TES prototype. The section on the TES concept provides a brief review of the relevant literature and current knowledge on this topic, defines the principle of operation of TES systems, and describes the modelling approaches typically used for their investigation. The section regarding KPIs presents the definitions and the formulas of the parameters utilised to measure the functioning of TES systems and evaluate the compliance of the prototype developed with the objectives of the ZHENIT project. The modelling overview outlines the main characteristics of the analytical model and the computational fluid dynamics (CFD) model developed to design the TES prototype. The former is a one-dimensional theoretical model of a latent heat thermal energy storage (LHTES) system solving the thermodynamics and fluid dynamics of heat exchangers (HEs) with multi-layer rectangular plates functioning with a heat transfer fluid (HTF) and a phase change material (PCM). The latter is a three-dimensional CFD model solving the Navier-Stokes governing equations and applying the solidification and melting method to determine the thermodynamics and fluid dynamics of the HTF and PCM in heat exchangers. The section on PCM selection describes the procedure that led to the choice of the RT80HC as the heat storage medium. Initially, the list of commercial materials suitable for the correct functioning

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in the operating conditions of the prototype is presented. This list is then narrowed down based on the melting temperature, latent heat of fusion, and average specific heat capacity. For these storage materials, the results of preliminary analyses conducted for standard configurations of the TES system are presented. Finally, the choice of PCM is explained based on the objectives of maximising energy storage capacity, mainly in the form of latent heat, and complying with weight limitations. The design of the TES prototype presents the geometric characteristics, operating conditions, and KPIs of the device intended for installation in the Tecnalia laboratory. Furthermore, this part presents the parametric simulations conducted with the analytical model to select the final TES configuration and indicates the effects of the main geometric and operating features on the performance of TES devices. Subsequently, the thermodynamics and fluid dynamics of the prototype are investigated through three-dimensional CFD analyses to enhance accuracy. Finally, the complete computer-aided design (CAD) model of the prototype is illustrated, and the design choices are explained in light of existing weight and manufacturing constraints. The section on the prototype realisation details all the materials, components, assemblies, and sub-assemblies required for constructing the prototype, along with their associated costs. For each component, information is provided on the part number, description, quantity, material, cost, assembly instructions, and supplier details. Moreover, the assembly process of the prototype performed in the Tyseley Energy Park of The University of Birmingham is described. The section on the commissioning tests presents the results of the experiments conducted on the TES prototype. These tests confirmed the absence of water leaks and verified the correct functioning of the system. Furthermore, the time series of the main thermodynamic and fluid dynamic parameters are presented for the various configurations tested at different stages of the prototype assembly. The conclusions delineate the objectives of the ZHENIT project and summarise the models developed to design the TES prototype, as well as the main results and discoveries attained through the presented research. An interpretation of the outcomes is provided, elucidating their significance in the context of waste heat utilisation on board vessels.

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D3.4 CFD models of eSAIL influence on the overall vessel efficiency (B4B)

The ZHENIT project, funded by the European Union's Horizon Europe program, stands at the forefront of Europe's drive to decarbonize maritime transport and accelerate the transition to climate-neutral shipping. Anchored in the EU Green Deal and the International Maritime Organization's (IMO) decarbonization roadmap, ZHENIT's overarching vision is to enable a new generation of "zero waste heat" vessels. The project's macro objectives are to achieve at least a 25% reduction in vessel energy consumption, maximize the recovery and utilization of onboard waste heat, and integrate advanced hybrid propulsion systems—most notably, wind-assisted technologies—into commercially viable, scalable solutions for the global fleet. Central to ZHENIT's strategy is the holistic integration of waste heat recovery (WHR) systems , digital energy management, and wind-assisted propulsion. The project's ambition is not only to reduce greenhouse gas emissions and fuel consumption during navigation but also to extend these benefits to hoteling and harbor operations, thereby supporting the EU's climate neutrality targets for 2030 and beyond. ZHENIT's approach is grounded in the development, validation, and demonstration of ready-to-implement solutions that can be rapidly replicated across diverse vessel types and operational scenarios, ensuring both environmental impact and market scalability Within this strategic framework, the recent achievements in computational fluid dynamics (CFD) modeling and wind tunnel testing—particularly as applied to bound4blue's eSAIL® wind-assisted propulsion system—represent a critical technological pillar of ZHENIT's integrated approach. The eSAIL®, a modernized suction sail leveraging active boundary layer control, is designed to generate significantly higher lift than conventional sails with minimal power input and mechanical complexity. The project's technical milestones include the development and validation of sophisticated 3D CFD models for both single and multi-sail configurations, the optimization of key aerodynamic parameters such as suction grid design and winglet geometry, and the rigorous empirical validation of these models through extensive wind tunnel campaigns at leading research institutions, including the Politecnico di Milano. These technical achievements have been directly translated into real-world impact through the installation of eSAIL® systems on commercial vessels, such as the Amasus Eems Traveller. This operational deployment not only validates the technology under actual maritime conditions but also addresses practical considerations such as manufacturing, maintenance, and ship-specific integration. The generation of comprehensive performance data and the development of trimming strategies ensure that the technology is robust, adaptable, and optimized for diverse routes and vessel types. The integration of

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wind-assisted propulsion with advanced WHR systems—such as Organic Rankine Cycles (ORC), adsorption cooling, and trigeneration—maximizes the utilization of onboard waste heat, further enhancing overall vessel efficiency. This synergy is central to ZHENIT's macro objective of achieving up to 25% energy savings per vessel, a target that, if scaled across the global fleet, could yield annual fuel savings exceeding 40 million tons and CO2 emissions reductions of approximately 120 million tons. In summary, the CFD and wind tunnel testing activities within ZHENIT exemplify the project's holistic, systems-based approach to maritime decarbonization. By delivering validated, high-impact technologies that integrate wind-assisted propulsion with advanced waste heat recovery, ZHENIT not only advances the technical frontier but also provides a scalable, market-ready pathway to achieving the EU's and IMO's climate objectives. The project's focus on innovation, practical deployment, and regulatory alignment sets a new benchmark for for sustainable shipping and provides a clear roadmap for the industry's transition to a low-carbon future.

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D3.5 Integrated numerical platform for dynamic simulations and numerical results (NTUA)

The ZHENIT project develops innovative solutions to reduce wasted thermal energy aboard large vessels by converting it into useful onboard output, thereby improving energy efficiency and reducing emissions. Deliverable D3.5 presents a dynamic modelling framework and control logic for integrated Waste Heat Recovery (WHR) systems applicable to cargo and cruise vessels, focusing on three technologies of the ZHENIT portfolio: an exhaust-gas-driven Organic Rankine Cycle (ORC) and two jacket-cooling-water-driven systems, the Isobaric Expansion Engine (IEE) and the Sorption Desalination Chiller (SDC). All systems are coupled with a sensible buffer tank and a latent thermal energy storage (LTES) unit to enhance waste heat utilization under transient conditions. A fully dynamic model was developed in TRNSYS to simulate the coupled behaviour of the WHR architecture, storage components, and control strategies using realistic operating profiles of a cruise vessel with highly variable loads and a cargo vessel with quasi-steady conditions. The framework was used to evaluate the effects of technology scale and storage sizing on energy production, fuel savings, economic benefits, and CO_2 emissions reduction. Independent modelling of each technology was adopted to ensure physical consistency, while combined configurations were assessed to estimate the overall potential of multi-temperature waste heat recovery. For the cruise vessel, thermal storage is essential due to strongly fluctuating heat availability. Increasing tank and LTES capacities significantly improves performance, especially when both EG and JCW streams are exploited. The ORC dominates overall energy production, while JCW-based systems provide additional savings. In combined configurations, electricity production reaches approximately 7,300–7,800 kWh per trip at small scale and 22,000–23,500 kWh per trip at large scale when the IEE is used, with higher equivalent fuel and emissions savings achieved when the SDC supplies cooling. For the cargo vessel, characterized by stable waste heat sources, storage sizing has only a minor influence on performance. Systems operate near continuously even with limited storage, and performance is mainly constrained by heat availability. Combined ORC–IEE configurations yield about 4,750–4,950 kWh and 13,800–14,200 kWh per trip for small and large scales, respectively, while ORC–SDC configurations provide higher equivalent savings due to cooling production, with similarly weak sensitivity to storage capacity. The results confirm that storage primarily stabilizes operation rather than increasing energy recovery for steady profiles, whereas it is critical for transient conditions. The buffer tank mitigates short-term fluctuations, while LTES supports longer-term energy shifting. The

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IEE offers compact integration with modest output, whereas the SDC delivers higher benefits when cooling demand exists, making the technologies complementary. Overall, Deliverable D3.5 demonstrates that optimal WHR design is strongly vessel-specific and requires dynamic, control-oriented analysis. The developed modelling platform can support onboard Energy Management Systems, technology sizing for newbuild vessels, and retrofit decision-making, providing a robust basis for further integration studies within the ZHENIT project.

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D3.6 Control platform for the lab and on-board tests (SIGLA)

The D3.6 deliverable describes the development of a PLC-based control platform designed to manage and coordinate waste heat recovery systems within both laboratory and onboard environments. The platform translates predefined control strategies into a real-time automation framework, enabling the effective management of multiple interconnected subsystems through a modular and scalable architecture. At its core, the system relies on a programmable logic controller compliant with industrial standards, ensuring interoperability, maintainability, and flexibility in integrating heterogeneous technologies. The control architecture follows a layered approach, where field devices communicate with the controller through open protocols, while higher-level supervision systems interact via standardized interfaces, enabling seamless data exchange and monitoring capabilities. A key aspect of the platform is the implementation of a structured control philosophy based on finite state machine logic, which governs system behavior by coordinating operational states, managing transitions, and ensuring deterministic responses to process conditions. The software design emphasizes clear separation between input acquisition, control processing, and output generation, allowing efficient handling of commands, measurements, and actuator control. Additionally, the platform supports both automatic and manual operation modes, ensuring operational flexibility during testing, commissioning, and normal operation. To validate the control logic and integration strategy, a Hardware-in-the-Loop approach was employed, enabling realistic simulation of field devices and system responses without requiring full physical deployment. This testing methodology allowed verification of communication protocols, coordination logic, and system robustness under different operating scenarios. The overall design prioritizes modularity, enabling each subsystem to be managed independently while remaining fully integrated into the global control structure. This approach facilitates scalability, simplifies future extensions, and supports iterative refinement during development. Overall, the control platform represents a robust and adaptable solution for managing complex energy systems, contributing to improved operational efficiency and supporting the progressive validation and deployment of waste heat recovery technologies.

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D3.7 Enhancement and optimization of the control platform (SIGLA)

Deliverable D3.7 describes the maturation of the ZHENIT control platform from an initial integration framework into a more robust and structured automation solution able to support laboratory validation and, progressively, the transition toward operational use during on-board and sea-trial activities. The objective of the present expanded draft is to consolidate the information scattered across the available project files into a coherent report that explains why the control platform was enhanced, what technical decisions were adopted, and how those decisions supported the integrated management of the different waste-heat-to-X subsystems. The available source material shows a clear development path. On the monitoring side, Task 3.2 evolved from the idea of an energy monitoring platform into a more complete supervision environment capable of collecting measured data and control/state parameters from the technology developers, exchanging data with the SIGLA control platform, and preparing the calculation of KPIs and CO2-recovery indicators where applicable. On the control side, Task 3.6 advanced from the transposition of dynamic models into PLC logic toward a single configurable control platform for integrated tests, with hardware-in-the-loop engineering work, package coordination, emergency shutdown handling, communication protocols, and test HMI pages. The material further indicates that the enhancement work was not limited to software coding. It also included the clarification of boundary conditions, the review of scenario management, the definition of communication telegrams, the implementation of state-based behavior, and the refinement of interlocks and permissives required by the different WHx systems. This evolution is consistent with the control architecture described in D4.4, where SIGLA PLCs interact with the laboratory infrastructure and prototype developers through a communication framework designed to support integrated monitoring and control. The sea-trial screenshots available for this drafting exercise provide valuable evidence of the practical direction of the work. They show a structured HMI environment with launcher access, overview pages, synoptic screens, live process variables, and utility states. Although the screenshots alone do not replace a full testing log, they demonstrate that the enhancement effort effectively materialized in operator-facing pages able to support commissioning, observation of process variables, and the supervised operation of the integrated platform. Overall, the main outcomes of the enhancement activity can be summarized as follows: consolidation of a finite-state-machine-oriented control philosophy; completion of the main package control tasks; implementation of a customizable ESD matrix; setup of communication protocols based on MODBUS TCP/IP and S7 communication; first realization of supervision pages; management

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of motors and valves; and the progressive preparation of historical data, trends, and KPI-oriented views. The remaining actions are mainly related to the final integration of all WHx information, scenario optimization according to updated boundary conditions, refinement of inlet-heat regulation, and execution of additional test phases after the applied changes.

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D4.2 Laboratory test site completely prepared for the integration of prototypes (TECNALIA)

The ZHENIT Project aims to advance Waste Heat Recovery (WHR) as a key enabler for achieving the 2030 decarbonization targets established by the International Maritime Organisation (IMO) and the European Union. By leveraging innovative technologies and system integration, ZHENIT contributes to reducing greenhouse gas emissions in the maritime sector while enhancing energy efficiency and operational sustainability. The project focuses on the development, validation, and replication of advanced WHR solutions suitable for different ship types and operational conditions. Its scope includes the design and testing of new technologies, on-board validation campaigns, regulatory framework analysis, and the creation of a roadmap for large-scale replication at technical, economic, and regulatory levels. Within ZHENIT, multiple WHR technologies are being investigated, each addressing different waste heat sources and temperature levels. The key technologies include:

- Organic Rankine Cycle (ORC) systems for high- to medium-temperature heat recovery.
- Thermal Energy Storage (TES) for load management and improved system flexibility.
- Sorption Desalination and Refrigeration for the combined production of fresh water and cooling using waste heat.
- Isobaric Expansion Engine (IEE) for direct mechanical-to-electrical energy conversion from low-grade heat sources.

This document, Deliverable 4.2, corresponds to Task 4.2 of the ZHENIT project and focuses on the engineering and commissioning activities carried out at TECNALIA's laboratory. It details the integrationof the different prototype modules, the control and monitoring system architecture, and the preparatory steps for validation campaign in Task 4.4. These activities represent a step toward demonstrating the technical feasibility, performance, and interoperability of the ZHENIT WHR technologies under realistic laboratory conditions.

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D4.3 Pilot vessel completely prepared for the integration of the demo technologies (RINA-S)

The D4.3 deliverable describes the preparation and adaptation of the pilot vessel for the integration and validation of advanced waste heat recovery technologies under real maritime operating conditions. The activities focused on enabling the installation of a sorption-based prototype while preserving the integrity and operational functionality of the host vessel. A systematic approach was adopted, beginning with detailed onboard assessments to identify suitable thermal, mechanical, and electrical interfaces, followed by targeted modifications to the existing infrastructure. In particular, the integration strategy relied on a low-intrusion philosophy, leveraging existing systems such as the engine cooling circuit to supply thermal energy, while minimizing structural alterations and ensuring reversibility of the installation. Dedicated piping, pumping, and electrical arrangements were introduced to support the prototype, alongside structural reinforcements for safe positioning and fastening on deck. The vessel layout and configuration were carefully analyzed to ensure compatibility with stability, safety, and operational constraints. Particular attention was given to the integration of auxiliary systems, including seawater supply, instrumentation, and data acquisition interfaces, allowing continuous monitoring of key operational parameters. Following installation, a comprehensive onboard testing campaign was conducted to validate system performance in real conditions, characterized by dynamic loads, variable engine operation, and environmental influences. The testing phase enabled verification of the correct interaction between the prototype and the vessel systems, as well as the assessment of thermal behavior and operational stability across different scenarios. The results demonstrated the feasibility of integrating such technologies on existing platforms, confirming that waste heat recovery solutions can operate effectively in real maritime environments. Overall, the work provides a solid basis for future implementation and scaling of onboard energy efficiency technologies, supporting the transition toward more sustainable and resource-efficient maritime operations.

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D4.4 Report on the operation, monitoring and data analysis of the integrated prototypes at TECNALIA lab (TECNALIA)

Deliverable D4.4, "Report on the operation, monitoring and data analysis of the integrated prototypes at TECNALIA lab", summarizes the results of the experimental validation of the ZHENIT prototypes carried out within Work Package 4 and delivered at Month 47 (M47). The work aimed to assess the performance, integration, and control of the four core technologies developed in ZHENIT — the Organic Rankine Cycle (ORC), Thermal Energy Storage (TES), Adsorption Module (AM), and Isobaric Expansion Engines (IEE)— through a coordinated testing campaign at TECNALIA's laboratory in Azpeitia (Spain). The laboratory setup allowed reproducing representative onboard thermal conditions, enabling the evaluation of different technology combinations and operating modes. Testing activities covered both stand-alone and integrated operation, supported by a centralized monitoring and control system that applied optimized strategies for thermal energy management. The resulting datasets provided the basis for evaluating energy efficiency, system interoperability, and control stability, as well as identifying practical constraints and areas for improvement. The experimental findings confirm the technical viability of the integrated concept and indicate a significant potential for energy savings, contributing toward ZHENIT's objective of achieving a 20% reduction in vessel energy consumption. The report also captures key lessons learned and recommendations to guide future large-scale implementation. The document compiles the testing methodology, monitoring approach, and data analysis, and has been developed in close collaboration with all ZHENIT prototype developers, ensuring alignment with project-wide results and objectives. The sub-objective SO2.1 has been fully achieved, including objectives i) and ii):

i. Up to 90% of the available waste heat (WH) has been valorized through effective management of WH flows at different temperature levels using various ZHENIT WH-to-X solutions.

ii. A total of over 500 hours of testing have been completed at the TECNALIA Thermal Systems Lab, meeting the specified target.

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D4.5 Report on the operation, monitoring and data analysis of the pilot vessel WH system (RINA-C)

The present report constitutes the deliverable D4.5, named "Report on the operation monitoring and data analysis of the pilot vessel WH system", produced within Work Package 4 (WP4) of ZHENIT project, and delivered at M49. The main intention of the report is to assess the technical performance, perational feasibility, and energy efficiency impacts of waste-heat-related and wind-assisted solutions under real maritime operating conditions, supporting their evaluation for future replication. Two pilot applications have been analysed. The first concerns an adsorption-based refrigeration and desalination (SR&D) system installed on the fishing vessel TESEO, aimed at exploiting low-grade waste heat to provide cooling services and freshwater production. The second application concerns the installation of rigid suction sails (eSails) on the general cargo vessel EEMS Traveller, designed to harness wind energy to reduce main engine load and fuel consumption. In both cases, dedicated onboard monitoring systems were used to collect operational data and support the calculation of key performance indicators (KPIs) defined within the ZHENIT validation framework. The results show that, despite non-optimal and constrained operating conditions, both technologies demonstrated reliable functionality and clear potential benefits. For the fishing vessel, the SR&D system confirmed the technical feasibility of producing cooling and freshwater using waste heat, with very low electrical consumption, highlighting the suitability of adsorption-based solutions for energy-intensive auxiliary services on small vessels. Identified performance limitations were mainly related to integration and operational constraints rather than to the core technology itself. For the cargo vessel, the eSail system exhibited strong aerodynamic performance, achieving a measurable reduction in main engine load and demonstrating good compatibility with commercial operations.

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D5.4 Envirionomics assessment of ZHENIT Solutions: CBA, LCA and LCC (RINA-C)

The ZHENIT project aims to exploit waste heat recovery potential on-board vessels using energy management methods, clean energy solutions and low-emissions ship services. The targets of the project are new technologies development, on-board validation, a regulatory framework analysis and a replication roadmap at regulatory and economic level. Various waste heat recovery technologies will be paired synergistically, and the experience gained with this project in holistically integrating and managing different 'ready-to-go' WH-to-X systems, hybrid propulsion technologies, and energy management methods could be leveraged for future application in near zero waste-heat vessels. Various technological options for the recovery of marine engine waste heat are currently or potentially available. The purpose of this report is to study the environmental and socio-economic benefits and/or burdens arising from the installation of ZHENIT technologies on-board of different kind of vessels. Firstly, the operating principles for each technology will be described. Secondly, the methodological framework adopted for the three assessments (LCA, LCC and CBA) will be presented. Following this methodological introduction, the assessment process for each technology will be illustrated in detail, together with the results obtained when the technologies are evaluated individually (the so-called vertical analysis) and when they are integrated on board the vessels (the horizontal analysis).

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D5.7 TRL9 Roadmap including Social and regulatory assessment of ZHENIT solutions (RINA-C)

The ZHENIT project seeks to tap the onboard potential of waste-heat recovery by applying advanced energy-management approaches, clean-energy technologies, and low-emission maritime services. Its objectives are to develop new technologies, validate them on vessels, examine the regulatory landscape, and produce a replication roadmap covering both regulatory and economic aspects. Complementary waste-heat recovery solutions will be combined in a coordinated way, and the expertise gained in integrating and controlling mature WH-to-X systems, hybrid propulsion, and energy-management strategies will pave the way for future deployment on vessels operating with near-zero waste heat. The current deliverable offers the "TRL9 Roadmap, which includes a social and regulatory assessment of ZHENIT solutions," to facilitate the maturation and market adoption of ZHENIT solutions until they reach full operational readiness. Particularly, the document offers a practical perspective on how to transition ZHENIT solutions to TRL9 and fleet-wide deployment. It transforms the project's innovations into a sequential pathway that includes on-board integration requirements, success criteria, and milestones. The Social Assessment proposes concrete measures to facilitate adoption, highlighting the impacts on personnel and stakeholders, skill requirements, safety, and acceptability. The Regulatory Assessment delineates the actions necessary to address gaps and expedite commissioning by mapping applicable regulations, class requirements, and certification pathways. These components, when combined, de-risk final validation, guarantee operational reliability, cyber-safety, and interoperability, and establish protocols for energy and emissions monitoring and verification. This yields a roadmap that is both market-ready and straightforward for replication and scaling up in order to achieve near-zero waste-heat vessels.

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D5.8 Market assessment of ZHENIT Solutions identifying preliminary business models (RINA-C)

ZHENIT solutions represent a comprehensive approach to improving energy efficiency and sustainability in the maritime sector by integrating waste heat recovery technologies, digital systems, and innovative propulsion concepts. The technologies developed within the project demonstrate strong alignment with global decarbonization strategies and respond effectively to increasing regulatory pressure and rising operational costs in shipping. In particular, the combination of thermal, mechanical, and digital solutions enables a more efficient use of onboard energy, contributing to reduced fuel consumption and lower greenhouse gas emissions. Despite this strong potential, the level of technological maturity varies across the different solutions, and several of them still require further validation in real operational environments. Demonstration activities, scale-up efforts, and performance optimization will be essential to ensure reliability and competitiveness in the market. In addition, compliance with maritime classification standards and other regulatory requirements remains a key prerequisite for successful adoption. From a business perspective, the solutions show promising opportunities through a range of models, including equipment sales, service-based approaches, and digital platforms. The involvement of multiple stakeholders such as shipowners, shipyards, and technology providers highlights the importance of collaboration and ecosystem development in facilitating commercialization. Overall, while the technologies present clear value propositions and market relevance, future progress will depend on overcoming technical and regulatory barriers and strengthening industrial partnerships to support their large-scale deployment.

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D6.3 ZHENIT Preliminary Dissemination and Communication Plan (RINA-C)

The ZHENIT Project aims to promote Waste Heat Recovery (WHR) as key and "ready-to-implement" solutions to achieve 2030 International Maritime Organisation and European Union targets for shipping sector decarbonization. ZHENIT goal is to fully untap "on-board WH potential" developing and validating WHR solutions at different temperature levels for different on-board services (cooling, power, desalination), thus promoting heat in different vessel processes. The present document constitutes the Deliverable D6.3 "ZHENIT Preliminary Dissemination and Communication Plan", developed within Work Package (WP) 6, which gives an introduction of the preliminary steps of the communication and dissemination activities (to be performed in the framework of Work Package 6) in terms of strategy, tools' development, website design, social media and it serves as a blueprint as well as internal practical guide for the members of the consortium for engaging with the dissemination activities in the framework of the ZHENIT project. The definition of a preliminary communication and dissemination plan for the suitable promotion of the project, such as identification of agreed dissemination measures/procedures/channels, dissemination events, stakeholder's engagement, definition of a target audience and events, is one of the key activities to guarantee a proper project promotion and the achievement of the expected impacts.

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D6.4 ZHENIT Dissemination and Communication Plan – Update (RINA-C)

The ZHENIT Project aims to promote Waste Heat Recovery (WHR) as key and "ready-to-implement" solutions to achieve 2030 International Maritime Organisation and European Union targets for shipping sector decarbonization. ZHENIT goal is to fully untap "on-board WH potential" developing and validating WHR solutions at different temperature levels for different on-board services (cooling, power, desalination), thus promoting heat in different vessel processes. The present document constitutes the Deliverable D6.4 "ZHENIT Preliminary Dissemination and Communication Plan", developed within Work Package (WP) 6, which gives an introduction of the preliminary steps of the communication and dissemination activities (to be performed in the framework of Work Package 6) in terms of strategy, tools' development, website design, social media and it serves as a blueprint as well as internal practical guide for the members of the consortium for engaging with the dissemination activities in the framework of the ZHENIT project. The definition of a preliminary communication and dissemination plan for the suitable promotion of the project, such as identification of agreed dissemination measures/procedures/channels, dissemination events, stakeholder's engagement, definition of a target audience and events, is one of the key activities to guarantee a proper project promotion and the achievement of the expected impacts.

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D6.8 First Exploitation Report and KERs identification (RINA-C)

The ZHENIT Project intends to promote Waste Heat Recovery (WHR) as a major and "ready-to-implement" option for meeting the 2030 International Maritime Organization (IMO) and European Union decarbonization objectives for the maritime sector. ZHENIT's mission is to completely unlock "on-board WH potential" by creating and verifying WHR solutions at various temperature levels for diverse on-board services (cooling, electricity, desalination), hence encouraging heat in various vessel operations. The present document constitutes the Deliverable D6.8 "First Exploitation Report and KERs identification", developed within Work Package (WP) 6, which provides an introduction to the preliminary steps for the exploitation and Intellectual Property Right (IPR) protection of ZHENIT's results. The document includes the draft exploitation strategy, the tools developed and used, and all the actions dedicated to the first characterization of the key exploitable results. Future updates of the present deliverable will serve as a guide for the members of the consortium for planning all the actions to properly exploit and protect their results in the framework of the ZHENIT project and after its end.

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D6.9 ZHENIT Dissemination and Communication Plan - Update 2 (RINA-C)

The ZHENIT Project aims to promote Waste Heat Recovery (WHR) as key and "ready-to-implement" solutions to achieve 2030 International Maritime Organisation and European Union targets for shipping sector decarbonization. ZHENIT goal is to fully untap "on-board WH potential" developing and validating WHR solutions at different temperature levels for different on-board services (cooling, power, desalination), thus promoting heat in different vessel processes. This document represents Deliverable D6.9, titled "ZHENIT Preliminary Dissemination and Communication Plan – Update 2", produced as part of Work Package (WP) 6. It outlines the latest updates to the project's communication and dissemination activities, detailing the strategic approach, social media engagement, and various outreach efforts. This updated plan reflects the project's ongoing commitment to effectively raising awareness and engaging stakeholders in WHR's benefits for sustainable maritime operations.

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D6.11 Final Exploitation Report and IPR management guidelines (RINA-C)

The ZHENIT Project intends to promote Waste Heat Recovery (WHR) as a major and "ready-to-implement" option for meeting the 2030 International Maritime Organization (IMO) and European Union decarbonization objectives for the maritime sector. ZHENIT's mission is to completely unlock "on-board WH potential" by creating and verifying WHR solutions at various temperature levels for diverse on-board services (cooling, electricity, desalination), hence encouraging heat recovery in various vessel operations. The present document constitutes the Deliverable D6.11 "Final Exploitation Report and IPR management guidelines", developed within Work Package (WP) 6 and provides a comprehensive overview of the Intellectual Property Management (and of the IP protection measures decided by the project partners) as well as of the Exploitaiton strategy of ZHENIT's results. The document includes the exploitation strategy, an overview of the procedures and rules applied for the knowledge management and a picture of the current intentions of the partners in relation to the IP measures that will be applied to ZENITH key exploitable results after the project ends. The deliverable serves as a guide to properly exploit and protect results under the framework of Horizon 2020 and Horizon Europe.

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D7.1 Executive Action Plan (RINA-C)

The ZHENIT Executive Action Plan provides a structured and coordinated framework to guide the development, validation, and deployment of innovative solutions aimed at reducing waste heat and improving energy efficiency in maritime transport. It establishes a comprehensive work breakdown structure that clearly defines tasks, timelines, and responsibilities across all project partners, ensuring alignment and effective collaboration throughout the project lifecycle. The project integrates advanced waste heat recovery technologies, including thermal, mechanical, and power generation solutions, together with digital monitoring platforms and thermal energy storage systems. This integrated approach enables a more efficient use of onboard energy streams, supporting the objective of achieving significant energy savings and reducing greenhouse gas emissions in line with global decarbonization targets. Activities are organized to follow a progressive pathway from initial vessel analysis and technology design to laboratory validation, on-board demonstration, and final impact assessment. This phased approach ensures that each solution is thoroughly tested, optimized, and prepared for real operational conditions, while also addressing market requirements, regulatory frameworks, and scalability considerations. In addition, the plan emphasizes strong governance, risk management, and communication mechanisms to support project execution. Dissemination and exploitation activities are designed to maximize impact, facilitating knowledge transfer, stakeholder engagement, and the future commercialization of the developed technologies. Overall, the plan represents a holistic strategy to enable the transition toward more sustainable and energy-efficient maritime operations.

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D7.2 Data Management Plan (RINA-C)

The present document D7.2 “Data management plan“ (M3) provides a plan for data management in the ZHENIT project, taking into account the data collected, generated and/or used in the different WPs over the duration of the project. It has been developed in the framework of WP7 activities (“Project Management, Monitoring and Assessment”) under the responsibility of the coordinator RINA Consulting. The purpose of the present document is to establish the mechanisms to handle research data during and after the project, outlining a preliminary strategy for the management of the data generated in the framework of ZHENIT project activities. Procedures for the management of research data, dataset description and scientific publication data will be addressed. The management policy will be defined fully in compliance with the open access principles adopted by the European Commission and enforced through the Grant Agreement. The present Data Management Plan has to be considered as a living document, and any future update or change in the ZENTIH data management policy will be included in the periodic reports or will be specified in the deliverables related to the specific tasks. The present deliverable is a live document and will be updated in M40 with the version D7.5 “Data Management Plan – final review”, extending and improving the identified information or including new datasets not identified in the present document.

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D7.3 Ethics Self Assessment (RINA-C)

The project's deliverable D7.3, "Ethics Self Assessment," aims to provide an overview of the ZHENIT project's ethically significant elements, with a special focus on personal data management techniques and environment, health, and safety characteristics of the project itself. The management policy shall be explicitly stated in compliance with the open access standards established by the European Commission and will be enforced through both the Grant Agreement and the Consortium Agreement. A preliminary plan for the ethical and proper management of some data collected in the project is also given in this deliverable.

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D7.4 ZHENIT risk matrix and project objectives/impacts KPI Panel for project reporting/tracking (RINA-C)

The aim of this Deliverable is to establish the necessary risk management protocols to guarantee the accomplishment of the project's goals. In research and innovaion projects this activity also includes the possibility that some of the paths for the achievement of the project goals cannot be used and it describes alternative ways to reach the expected results anyway. The main section of this document is the project's Risk Assessment and Contingency Plan, which outlines the tools and techniques used to monitor and track those events that may have the potential to affect the outcomes of the project and the project's weaknesses and vulnerabilities, prioritizing their impact and implementing appropriate security controls and countermeasures to mitigate them. It must be specified that risk management is a continuous activity that lasts throughout the whole duration of a project. It comprises procedures for planning, identifying, analyzing, monitoring, and controlling risks. Throughout the project lifecycle, many of these procedures are changed when new hazards can appear. Since new risks might be discovered at any time during the project lifecycle, many of these processes are updated.. The objective of risk management is to reduce the probability and impact of potential problems arising during a project. On the other hand, it is important to take advantage of any circumstance that could be advantageous. While risk is often associated with negative outcomes, it can also present opportunities. Risk can create opportunities for growth, innovation, and competitive advantage. When risks are properly managed, it is possible to take calculated risks that can lead to positive outcomes. This Deliverable will also include the first iteration of the KPI panel for the ZHENIT project. For the duration of the project, this tool will be continuosly updated in order to track the project's progress and in particular it will be modified in order to take into account the technological performance KPIs that will be defined in WP4 (Task 4.1 and Task 4.5) and in WP6 (Task 6.1) for those concerning D&C. The former will be presented, discussed and evaluated in the deliverables “D4.1 – KPI Definition and overall ZHENIT validation campaign strategy” and “D4.5 – Report on the operation, monitoring and data analysis of the pilot vessel WH system”.

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D7.5 Data Management Plan - final review (RINA-C)

The present deliverable D7.5 – Data Management Plan: Final Review provides the final, consolidated framework adopted by the ZHENIT Consortium for the management of data generated, collected and processed throughout the project duration. This version updates and replaces the initial D7.2 delivered at Month 4, integrating the developments achieved during the full lifecycle of the project and reflecting the revised project duration of 47 months established through the Amendment AMD-101056801-22 and the updated Description of Action. The Data Management Plan has been progressively refined in line with the evolution of technical activities, validation campaigns and replication studies. This final version presents a comprehensive overview of the datasets effectively produced across all work packages, including modelling and simulation data, laboratory and on-board experimental results, monitoring and control system outputs, techno-economic and environmental assessments, and information gathered through regulatory and stakeholder-oriented activities. The document confirms the adopted procedures for data classification, storage, access control and long-term preservation, ensuring full alignment with the FAIR principles and the Open Science requirements set by the Horizon Europe Model Grant Agreement. Compared to the preliminary strategy outlined in D7.2, this final version incorporates the updated list of datasets, the confirmed confidentiality constraints associated with industrial and safety-related information, and the operative configuration of the internal ZHENIT repository together with the external channels used for sharing non-confidential data. It also reflects the actual implementation of the TECNALIA laboratory campaign, the commissioning and operation of the on-board prototype on TESEO, the vessel used for the on-board validation campaign, and the deployment of the advanced monitoring and control tools developed within WP3. This deliverable is consistent with the ethical and data-protection framework established in D7.3 and ensures that all data-related processes remain compliant with the obligations defined in the Grant Agreement, including GDPR considerations. As such, this final DMP serves as the definitive reference for ZHENIT research data management and supports the project's long-term exploitation, replication and policy-oriented activities.

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