

D4.4 Roadmap for integrating new storage units onboard electric vessels

Document Identification			
Status	Final	Due Date	30 th of November 2025
Version	1.0	Submission Date	25 th of November 2025

Related WP	4	Document Reference	D4.4
Related Deliverables	D5.4	Dissemination Level	PU
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Keywords
Ship building, technology and integration roadmaps, rules and regulations, Formal Safety Assessment (FSA).

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Dissemination	PU	Version	1.0

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Acronyms

- SC - SuperCapacitors
- SMES - Superconducting Magnetic Energy Storage (System)
- SESS - Supercapacitor Energy Storage System
- ESS - Energy Storage System
- BESS - Battery Energy Storage System
- OSV - Offshore Service Vessel
- AHC - Active Heave Compensation
- PID - Public Interest Disclosure
- HMI - Human Machine Interface
- EMS - Energy Management System
- SoC - State of Charge
- DG - Diesel Generator
- SFOC - Specific Fuel Oil Curve
- AFE - Active Front End
- PCS - Power Conditioning System
- TRL - Technology Readiness Level
- EMC - Electromagnetic Compatibility
- HAZID - HAZard IDentification
- FSA - Formal Safety Assessment
- IMO - International Maritime Organisation
- SOLAS - Safety Of Life At Sea
- ADA - Alternative Design and Arrangements
- RCO - Risk Control Options
- RCM - Risk Control Measures
- CAPEX - CApital EXpenditures
- OPEX - OPERational EXpenditures
- FAT - Factory Acceptance Test
- HAT - Harbor Acceptance Test
- SAT - Site Acceptance Test
- DP - Dynamic Positioning

1 Introduction

This *Roadmap for integrating new energy storage units onboard electric vessels* contains the following main chapters:

- Shipbuilding process with supercapacitors and SMES
- Roadmaps for marine for the actual technologies
- Rules and regulations
- Formal Safety Assessment (FSA)
- Roadmap for integrating supercapacitors from Skeleton Technologies onboard vessels
- Roadmap for integrating SMES from ASG onboard vessels
- Conclusions

The document focuses on the vessel types selected in WP1 in this project:

1. Electric Ferry
2. Offshore Support Vessel (OSV)
3. Fishing Vessel

The roadmaps for integrating the technologies SC and SMES onboard vessels are based on the roadmaps for the specific technologies described in the project’s *D5.1 Market readiness level of different storage solutions and the next steps to increase the TRL*. Since D5.1 has dissemination level *sensitive*, and this document has dissemination level *public* the roadmap descriptions in D5.1 are included in this document.

The FSA is based on the risk assessment analysis of ESS carried out earlier in this project and both are focused on the OSV type of vessel.

All roadmaps in this document are based on the Technology Readiness Level (TRL) concept developed by NASA in the 1970s. In Figure 1 below there is a short description of the requirements to reach a certain TRL and the validation criteria for the TRLs that has been used in the analysis in this document.

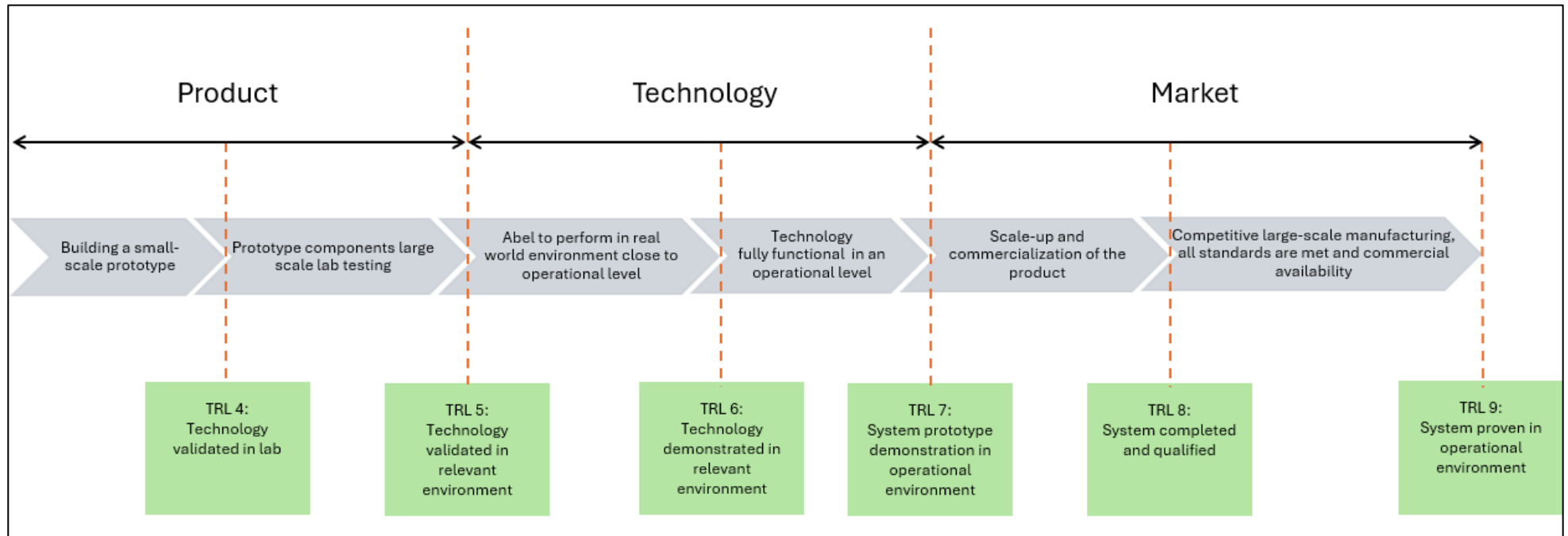


Figure 1: Technology Readiness Levels (TRL) overview

2 Shipbuilding process with supercapacitors and SMES

Figure 1 below shows the shipbuilding process with a SC/SMES system and the parties involved.

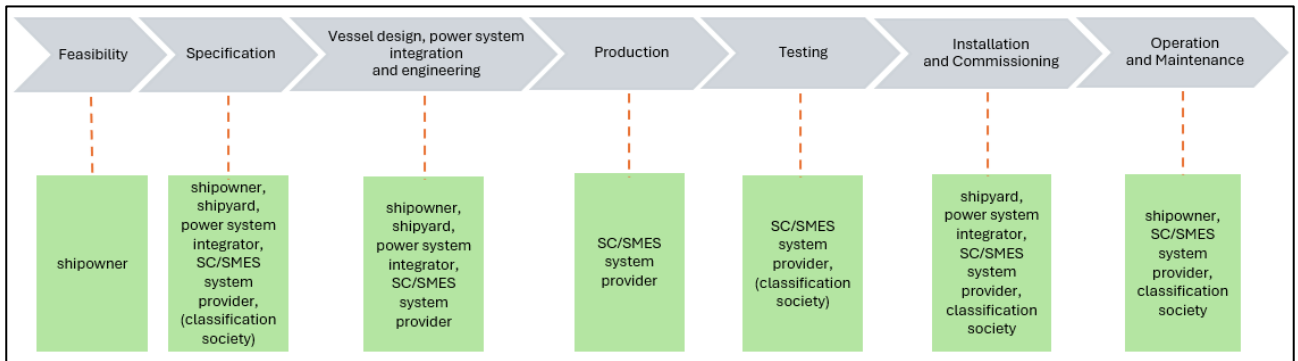


Figure 2: Shipbuilding process with a SC or SMES solution and the parties involved

In the process in Figure 1 the shipowner, the shipyard, the power system integrator, the SC/SMES system provider and the classification society are involved. If the SC/SMES solution has reached TRL 7 and is type approved by the classification society this will make the process simpler. The following is a short description of the focus in the phases in this process.

2.1 Feasibility

This is the phase where a potential installation of new technologies like SC and SMES is born. It is in the hands of the shipowner to decide which solution to choose and often there is communication between the shipowner and one or several shipyards and vessel design companies at this stage.

This communication is focused on:

- What are the benefits of the new solution compared to a traditional one?
- Is the new solution a “greener” solution (CO₂, NO_x, etc.)?
- Will the new solution be approved and certified in time?
- Changes in costs (CAPEX and OPEX) compared to a traditional solution?
- Will there be an impact on the time schedule of building the vessel?
- What is the impact on the operational procedures on the vessel, e.g. training and/or certification of crew?

2.2 Specification

The next step is to create a building specification for the vessel that contains the new solutions. This is normally a process starting with a tender specification from the shipowner containing detailed requirements for the vessel to be built.

From the tender specification the shipyard creates a draft version of the building specification. In this process the shipyard must contact many of its suppliers. Among these are the power system integrator and the SC or SMES system provider. If the SC or SMES solution is not type approved the classification society needs to be involved as well to get some advice for how to do the installation and integration for the solution to be approved at a later stage.

Based on the draft specification the discussion with the shipowner can start and through the period of finalizing the specification in its final version many important decisions must be made by the shipowner. Among these are the use of new solutions. The shipowner will consider many aspects when these decisions are made and one of these is the fact that the shipowner normally already has a fleet of vessels and it must be easy for any crewmember to work on any of these vessels. To accommodate this requirement the shipowner and the shipyard agree on a list of makers (“makers list”) stating the makers of the different systems that should be in the building specification and finally installed on the vessel.

This way of working is understandable from the shipowner’s point of view, but it makes it hard for new solutions to be selected and installed on a vessel. The specification process is where the battle of installing SC or SMES on a vessel will take place!

2.3 Vessel design, power system integration and engineering

When the building specification and the agreement between the shipowner and the shipyard is signed the detailed vessel design can start. Along with this the power system integration must start to make sure the required space for the power equipment and arrangements for ventilation, cooling, safety, etc. are in place. In this part the SC or SMES system provider will be involved.

When the design is “frozen” the engineering process for the designed solution can start. For the power system this is when the necessary cabling is defined. At the same time purchasing the necessary equipment starts because many of the components on a vessel have long production lead time. SC and SMES can be among these.

2.4 Production

When a SC or SMES manufacturer receives an order for a solution to be installed onboard a vessel the production can start. If the SC or SMES solution is type approved by the classification society production should be straight forward and result in a system that includes necessary arrangements to

accommodate the requirements for ventilation, cooling, redundancy, EMC/EMI, cabling, interfaces to EMS/PMS, safety instructions and documentation including installation, integration and user manuals. This way it will be easy to install the SC and SMES equipment onboard the vessel when it arrives at the shipyard.

2.5 Testing

Before the SC or SMES is sent to the shipyard it needs to be tested according to test-procedures described in the documentation for approval.

If the SC solution or SMES solution is type approved the produced entity can be tested in the factory according to the described test-procedure without any witness from the classification society. The shipyard and the power system integrator may in some cases have an interest in observing this test to ensure compatibility with the rest of the power system.

If the solution is to be case-by-case approved a Factory-Acceptance-Test (FAT) must be carried out according to the test-procedure described and witnessed by the classification society.

2.6 Installation and commissioning

After the solution is tested in the factory it will be shipped to the shipyard where it is installed onboard the vessel. Normally a Harbor-Acceptance-Test (HAT) will be carried out when the vessel still is at the shipyard to make sure the equipment still works after the shipment and to verify that the installation and integration with rest of the power system onboard works as expected. This test is normally a simple test without any witness. If something is not working, it is easier to fix it when the vessel is still in harbour at the shipyard.

When the vessel is ready there will be a sea-trial to test all systems and equipment onboard the vessel. At this sea-trial a Site-Acceptance-Test (SAT) will be performed. This test is the final test to verify that the SC or SMES solution works as intended. This SAT needs to be witnessed by the classification society. If the solution passes the SAT, it can be used in real operations with the vessel when it is handed over to the shipowner normally short time after the sea-trial.

2.7 Operation and maintenance

Often the shipowner already has a contract for the vessel when it is delivered from the shipyard, and the vessel goes directly into operation. If the SC or SMES passed the SAT at sea-trial this equipment can be used as intended when the power system was designed and power system integration was planned, e.g. as a spinning reserve in DP operations if this notation and rules have been implemented.

When the SC or SMES is integrated into a power system most of the usage will be taken care of by the Energy and Power Management Systems but some training on the new solution for the crew is needed. An important part of this is the maintenance plan for the new solution and to include this into the maintenance procedures onboard the vessel. The trend is that equipment suppliers offer online monitoring of their system to help the shipowner make full use of all benefits of the system, e.g. a PMS supplier can collect data online and advise on fuel optimization vs. system usage.

After a period depending on the type of vessel and what kind of operation it is built for it needs to be re-classified by the classification society to be allowed to continue its operation.

3 Roadmaps for marine for the actual technologies

3.1 Skeleton supercapacitor development roadmap

In the figure below the development roadmap for supercapacitors for Skeleton are shown.

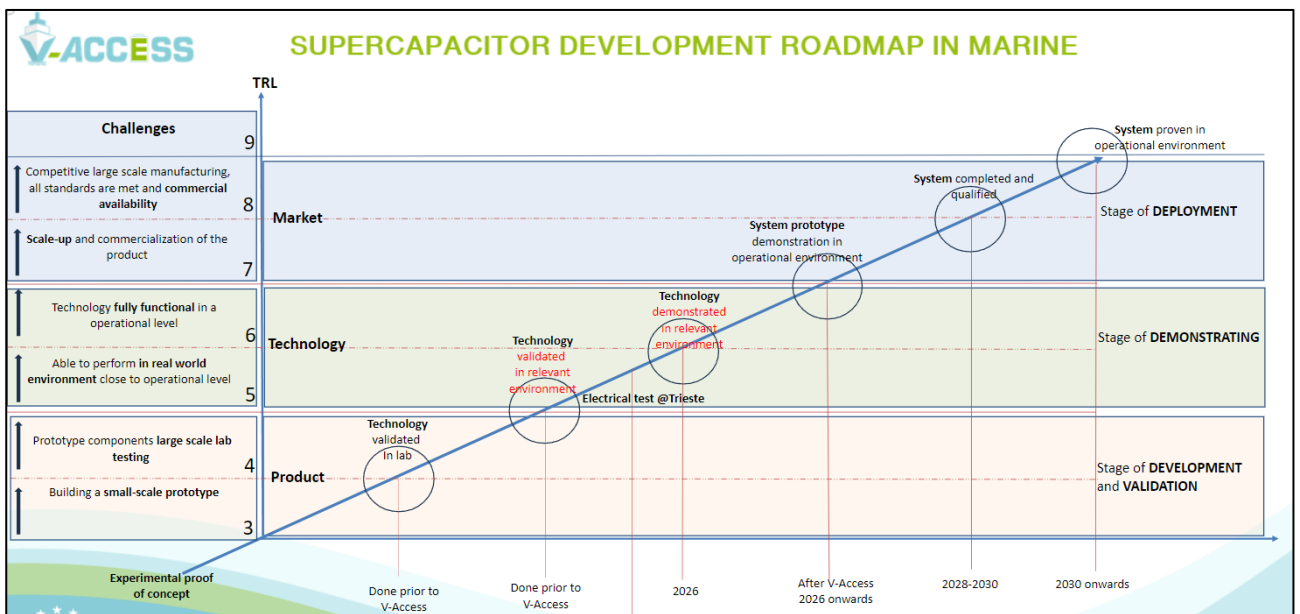


Figure 3: Roadmap for raising TRL in Marine for supercapacitor systems

Although the supercapacitor system is already mature technology, its implementation in marine segment is still on low TRL. There are several regulatory and other constraints that need to be overcome to successfully use supercapacitor systems on vessels. In V-ACCESS context Skeleton Technologies supercapacitor system (Skelgrid 2.0 rack-based platform) is on TRL 5, which means that prototype components (sub-systems) have undergone large scale laboratory testing and whole system is ready for marine specific (real world environment close to operational level) tests. The first objective and challenge are to prove that the whole prototype is reliable in the relevant environment. This objective will be reached during testing according to V-ACCESS project WP3 T3.5 plan. To reach TRL 6 the main challenge is to find the place and resources to test full prototype close to operational level

under controlled conditions and receive feedback to finetune first functional marine-specific version of the product.

Moving towards TRL 7 means that the stage of technology demonstration will be concluded, therefore the product needs to meet all operational and functional requirements to progress to the system demonstration stage. Main challenges between 6 to 7 is to test system successfully under real world conditions meaning whole system tests on actual vessels. Another time-consuming and costly process, which is a real challenge to new technologies, is product certification. For this strong market demand from potential customers and investors it is a necessity to progress there as quickly and market needs.

After TRL 7 and onwards a stage of deployment starts where the focus is on competitive manufacturing, which will be achieved through scale-up, commercialization and market strategy as well as emphasis on the readiness of the supply chain. More specifically the challenges between TRL 7 and 8 include acquiring system qualifications. This means all the technical documentation, compliance and certifications should be done so that focus can shift towards scale-up of production and product commercialization. A serious challenge to overcome is to find a qualified workforce who have experience in scaling up novel pilot productions. These skills are not so common in the EU market; therefore, it could be a significant obstacle to overcome. Another challenge is the lack of public funding that focuses on commercialization route for products that are novel and compete against conventional fossil-based solutions. In general technology development and even scale-up is being quite efficiently supported by the EU, however road-to-market and achieving compliance is clearly missing.

Reaching TRL9 and onwards it is all about competitive manufacturing and secure and efficient supply chains. This includes successful scale-up while maintaining supply chain security and access to a skilled workforce. Challenges are getting the costs down and having a clear market strategy. There are several areas where to implement supercapacitor systems in marine, each of the application areas having their own strengths and weaknesses against internal combustion engines or even electrical battery packs. It comes down to cost per kW and application time as was described in previous section about typical use cases in marine.

3.2 ASG SMES development roadmap

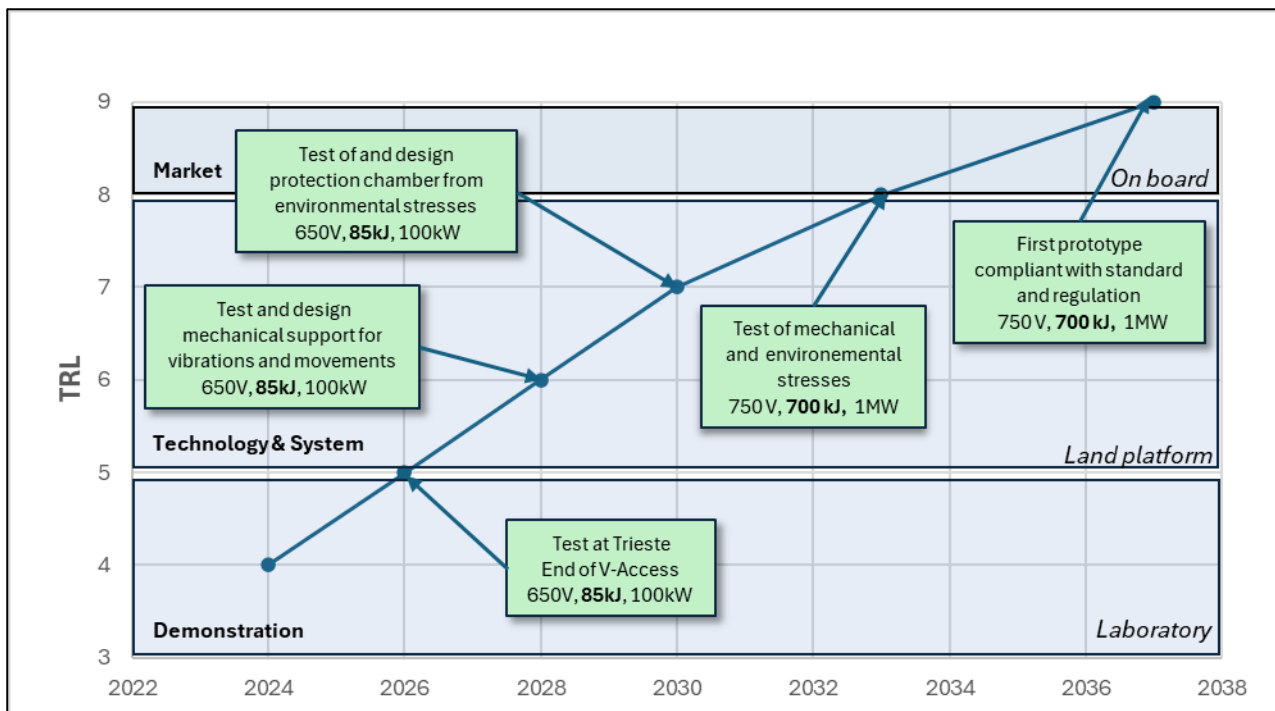


Figure 4: Roadmap for raising TRL in Marine for SMES systems

Although the SMES technology has been studied and demonstrated by the testing for more than 30 years, no large implementation has been yet realised. In any case the prototypes were designed and extensively tested with on-ground demonstrations in a similar or even higher power range. However, it has never been installed or implemented for the conditions of a ship. The timeline and required testing to achieve a TRL 9 envisioned is described into Figure 3.

As a starting point, ASG considers that the TRL 4 is reached as it is demonstrated already [1],[2],[3],[4]. It has been proven that different and repeated power profiles that include load and unload are manageable with SMES. The next level will be reached by testing the system that includes an adapted power converter in association with batteries. It will be done at the end of the V-ACCESS project on the Trieste test platform in collaboration with Trieste university during task 3.5. At the end of V-ACCESS project, an important step indicating that the SMES system can be proposed as an additional peak power source under low voltage of 650-750 V DC, the voltage on board of a ship. It will confirm the adequation of the SMES power source to the specific mission profiles on board a ship defined and tested. This work will be carried out on a smaller system up to 85 kJ that is in accordance with testing platform specification and budget of V-ACCESS project.

Hereafter a list of challenges reaching each technological readiness level is summarized:

TRL 3 to TRL 4 – Experimental proof of concept to technology validated in the laboratory

- Already demonstrated on a 20 kJ SMES system
- Lab tests & Computer simulations done

TRL 4 to 5 – Technology validated in lab to technology validated in relevant environment

- Validated after the completion by March 2026 (end of the V-ACCESS) of electrical power testing at Trieste on an 85 kJ 650 V SMES system, including:
 - o Definition of power profiles including ramp up, ramp down, multi levels.
 - o Acceptance of the safety procedure for the testing.
 - o Validation of the magnetic field compatibility (EMC) on the site and on-board a ship.
 - o Check the auxiliary connections (chiller, cooling fluid, electrical power...).

TRL 5 to 6 – Technology validated in relevant environment to technology demonstrated in relevant environment

- Validated by 2028 after the completion mechanical test simulating the stresses on board on an 85 kJ 650 V SMES system mechanically upgraded, including:
 - o Definition of relevant mechanical profiles including oscillation, shock, vibration (amplitude, frequency, number of cycles)
 - o Design and manufacture upgraded SMES system
 - o Identify the possible land testing platforms
 - o Design and manufacture the tooling for the testing
 - o Acceptance of the safety procedure for the testing
 - o Check the auxiliary connections (chiller, cooling fluid, electrical power...)

TRL 6 to 7 System prototype demonstration in an operational “environment “

- Validated by 2030 on land after the completion environment simulating the atmosphere (moisture, salt) on board on an 85 kJ 650 V SMES system mechanically upgraded, including:
 - o Definition of environment profiles including duration and atmosphere (composition, temperature)
 - o Design and prepare an environment protective enclosure that includes the SMES and its auxiliaries
 - o Identify the possible land testing platforms
 - o Design and manufacture the tooling for the testing
 - o Acceptance of the safety procedure for the testing
 - o Check the auxiliary connections (chiller, cooling fluid, electrical power)

TRL 7 to 8 - System completed and qualified

- Validated by 2033 after the completion of testing on land on an upgrade 700 kJ 750 V class SMES system mechanically compliant, including:
 - o Design and manufacture a mechanically compliant 700 kJ class SMES system in its protective enclosure
 - o Definition of testing profiles
 - o Identify the possible land testing platforms
 - o Design and manufacture the tooling for the testing
 - o Acceptance of the safety procedure for the testing
 - o Standard and regulation rules to be proposed

TRL 8 to 9 system proven in operational conditions

- Validated by 2036 after the completion of testing on board on a 700 kJ 750 V class SMES device
- Standard and regulation rules defined and accepted
- Identification of a test ships (Ferry, Trawler, OSV) and an end user/customer contractually committed
- Test according to missions predefined.

This schedule to increase the TRL for SMES can be shortened if necessary. Accelerating the identification and access of the different testing platforms and receiving information about the specifications to be considered in system preparation will help speed things up as well.

4 Rules and regulations

This project's D5.4 Rules Gap Analysis [5] states in its chapter 6:

... while existing maritime rules and international standards offer a solid foundation for the integration of conventional battery systems, both SMES and supercapacitor-based configurations remain only partially addressed within the current framework. This results in regulatory uncertainty for technology developers, ship designers, and operators seeking to adopt these emerging solutions at higher Technology Readiness Levels (TRLs).

Further D5.4 in chapter 6.1 Key Conclusions states:

- **Regulatory Coverage Gaps:** *Current standards (e.g., IEC 60092, IACS E10, and classification society rules for battery installations) provide partial coverage but do not fully encompass the unique properties of supercapacitors and Superconducting Magnetic Energy Storage (SMES) systems. SMES introduces additional challenges such as cryogenic operation, magnetic field containment, and quench protection, which remain outside existing maritime frameworks.*
- **Need for Technology Qualification:** *To ensure safe and reliable integration, Technology Qualification Processes (TQP) should be applied to verify the performance and failure modes of novel ESS technologies—particularly SMES and hybrid configurations—under realistic marine operating conditions.*
- **Alternative Design and Risk-Based Approaches:** *In the absence of prescriptive standards, the use of Alternative Design (SOLAS Regulation II-1/55) and risk assessment methodologies is essential to demonstrate equivalent levels of safety and compliance for innovative technologies such as SMES and supercapacitors.*
- **Harmonization Among Classification Societies:** *Differences in interpretation and requirements between classification societies highlight the need for a harmonized approach that covers both SMES and supercapacitor technologies, particularly regarding testing procedures, certification criteria, and installation guidelines.*
- **Pathway to TRL Advancement:** *Filling regulatory gaps and establishing qualification protocols for both SMES and supercapacitor systems will directly contribute to raising their TRL levels, facilitating their transition from prototype to operational stages within the maritime domain.*

The results from the *Regulatory Coverage Gaps* and the *Technology Qualification Process (TQP)* in the list above are needed to be able to finally type approve the Supercapacitor and SMES systems for installation onboard vessels. From experience we know this will take some time and is not needed until the systems are to enter TRL 8: System completed and qualified. To reach this level the systems must go through certain testing under real operating conditions and in this process the Alternative Design process in the list above must be used in e.g. pilot projects.

5 Formal Safety Assessment (FSA)

For the V-ACCESS consortium, RINA Hellas facilitated an internal workshop to evaluate and select Risk Control Measures (RCMs) for the installation on the Offshore Supply Vessel (OSV) of the following systems:

1. SMES: Superconducting Magnetic Energy Storage System
2. SESS: Supercapacitor Energy Storage System

The workshop has used input from the results of the Hazards Identification Study (HAZID) which was conducted in the context of the risk assessment analysis of ESS. The workshop considered only Risks that have been ranked with Medium and High-risk in the report from the risk assessment analysis of ESS. The overall process observed consistency with the IMO Formal Safety Assessment (FSA) methodology.

5.1 Background

Formal Safety Assessment (FSA) is a structured and systematic methodology aimed at enhancing maritime safety, including protection of life, property, and the environment. IMO has issued detailed guidance on how to use the methodology, which are included in document MSC-MEPC.2/Circ.12/Rev.2. These Guidelines highlight that for the FSA to be consistently applied it is important that the process is clearly documented and formally recorded in a uniform and systematic manner. This will ensure that the FSA process is transparent and can be understood by all parties irrespective of their experience in the application of risk analysis and cost-benefit assessment and related techniques.

The key steps of the FSA methodology as per IMO guidelines are:

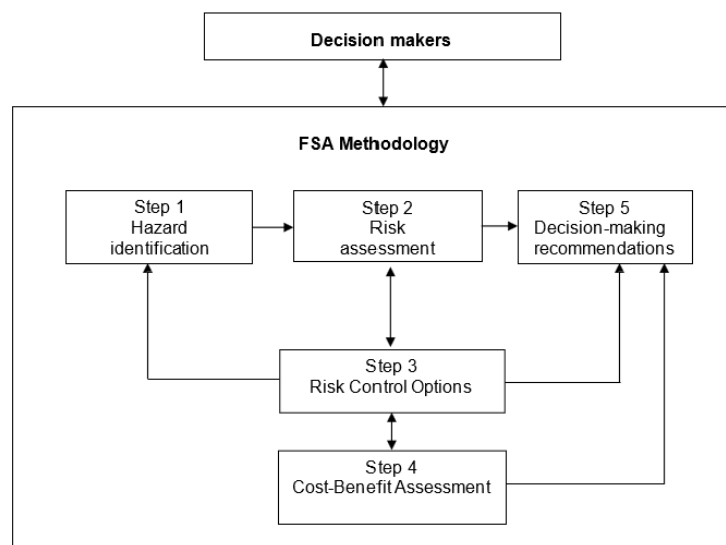


Figure 5: Flow Chart of the FSA methodology (source: MEPC.2/Circ.12/Rev.2)

In the context of the risk assessment analysis of ESS report, Step1 (HAZID) of FSA has been fully completed. Step2 (Risk assessment) has been performed in the risk assessment analysis as well, including likelihood/severity rankings. However, for some hazards the step 2 has not been completed. Steps 3, 4, and 5 are performed in this study. Therefore, this study will form an internal experts' group to perform the missing parts of the FSA for the SMES and SESS systems onboard the OSV vessel.

A Risk Control Option, RCO is a strategic option or broad approach proposed to reduce risk. It is identified during Step 3 of the FSA process, which is the "Identification of Risk Control Options."

- It is conceptual or high-level
- It addresses how risk might be reduced, but not necessarily the exact details, and
- Multiple RCOs can be identified to address a single risk.

Examples of RCOs (from the FSA guidance) grouped in four categories are shown in the following table.

Subsystem	Risk Control Options
Technical/Engineering	- Ergonomic design of equipment and workspaces- good layout of bridge and machinery spaces- Ergonomic design of man-machine interfaces- Specification of information requirements for crew- Clear labelling and instructions on ship systems and control equipment
Working Environment	- Ship stability and effect on crew (pitch/roll)- Weather effects (e.g., fog on watch-keeping)- Ship location (open sea, port approach)- Appropriate lighting for operations (day/night)- Consideration of noise levels (communication)- Temperature and humidity effects on performance- Vibration effects on task performance
Personnel	- Development of training programs for crew- Crew levels and makeup- Addressing language and cultural issues- Workload assessments (avoid underload/overload)- Motivational and leadership strategies
Organizational/Management	- Policies on recruitment, training, competency- Development of operational/emergency procedures (e.g., tug and salvage)- Implementation of Safety Management Systems (SMS)- Provision of weather forecasting/routing services

Table 1: Examples of RCOs from the FSA Guidelines

A Risk Control Measure, RCM is the specific implementation or practical realization of an RCO. It is typically selected after evaluating RCOs in Step 4 of the FSA: Cost-Benefit Assessment.

- It is detailed and actionable.
- It includes technical, procedural, or operational changes.
- It is what is done to control or reduce risk.

RCMs should in general be aimed at one or more of the following:

- reducing the frequency of failures through better design, procedures, organizational polices, training, etc.;
- mitigating the effect of failures, to prevent accidents;
- alleviating the circumstances in which failures may occur; and
- mitigating the consequences of accidents

5.2 Codes, Standards and Guidelines

The analysis presented in this document has observed the codes, standards and guidelines included in the following Table.

RINA Guide 15 Guide for Risk Analysis
ISO 31010 Risk management - Risk assessment techniques
ISO 3100 Risk Management - Principles and Guidelines
SOLAS Ch.II-1 and Ch. II-2
RINA Class Rules for Type Approval
RINA Rules for the Classification of Ships Part C Machinery, Systems and Fire Protection
Revised Guidelines for FSA (MSC-MEPC.2/Circ.12/Rev.2)
DNV-RP-0580: "Recommended Practice for Fire Safety in Battery and Energy Storage Installations"
ABS "Guide for Use of Supercapacitors in the Marine and Offshore Industries"

Table 2: Applicable Rules, Standards and Guidelines

5.3 Terminology

ALARP	The point at which the effort to introduce further reduction measures becomes unreasonably disproportionate to the additional risk reduction that will be obtained. The concept of ALARP may be qualitative or quantitative and, where necessary, guidance notes issued by the Authorities for application should be adopted.
ACCIDENT	An unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage.
CONSEQUENCE	Describes the results of an accidental event. The consequence is normally evaluated for human safety, environmental impact and economic loss.
FREQUENCY	Describes the number of expected occurrences per unit time of an event.
HAZARD	A condition in the workplace, equipment, or a method of carrying out an activity which has the potential to cause injury, illness and/or damages/loss to environment, to assets, property, production or some combination of these.
LIKELIHOOD	The expectation, possibility or chance of something happening; sometimes referred to as probability or frequency.
MITIGATION	Means taken to minimize the consequences of a significant accident to personnel, environment and installation after the accident has occurred.
PREVENTION	Means intended to prevent the initiation of a sequence of events, which could lead to a significant hazardous outcome. Such means include management systems applied to the design, engineering and construction standards, and the future operation of the installation, its inspection and maintenance.
RISK	The qualitative or quantitative likelihood of an accidental or unplanned event occurring, considered in conjunction with the potential consequences of such a failure.
RISK CONTROL MEASURE (RCM)	A means of controlling a single element of risk
RISK CONTROL OPTION (RCO)	A combination of risk control measures

Table 3: Terms used in FSA

5.4 Documentation

The FSA analysis presented in this document is based upon a design outlined in the below-mentioned concept drawings and technical specifications from the yard and the makers, as well results from previous work within the V-ACCESS project.

General:

- OSV General Arrangement

SMES: Superconductor Magnetic Energy Storage System

- SMES P&ID
- SMES Info Specs and Charact

SESS: Supercapacitor Energy Storage System

- Skeleton Data Power Point
- Skeleton Safety Data Sheet
- SkelGrid2.0 Integrators Manual 1
- Skelgrid2.0 components

HAZID Analysis:

- HAZID adapted Table for SMES from risk assessment analysis of ESS (including only Medium and High-Risk scenarios)
- HAZID adapted Table for SESS from risk assessment analysis of ESS (including only Medium and High-Risk scenarios)

5.5 Methodology

The objective of the methodology is the identification of Risk Control Measures (RCMs) for the risks that have been assessed as Medium or High in the HAZID study of risk assessment analysis of ESS. This will complete a high-level risk management work for the SMES and SESS onboard the case study vessel.

The focus of the expert's group was to select the RCMs, to assign attributes to these RCMs and finally evaluate their suitability and effectiveness. The prime purpose is to facilitate a structured thought process to understand how an RCM works, how it is applied and how it would operate.

The work of the experts is divided into the following Tasks.

Task 1: Select the RCM for Medium and High-Risk scenarios

This task corresponds to Step 3 of the FSA, namely the selection of Risk Control Options (RCOs). Within the context of the V-ACCESS project, it has been determined that generic RCOs are not applicable, as the identified risk scenarios are highly specific and require tailored RCMs.

The work of experts in this task is as follows:

- Re-evaluate the mitigation measures: Are they sufficient? What is missing?
- Re-express the “Recommendation” field into concrete, actionable RCMs.
- Reassess the final risk level assuming new RCMs are implemented.
- Consider ALARP principles — risk should be reduced as low as reasonably practicable (medium risk to low risk, high risk to medium risk).

Task 2: Assign attributes to the selected RCMs

The experts are asked to assign attributes to the selected RCMs according to the FSA Guidelines:

1. *Preventive risk control* is where the risk control measure reduces the probability of the event.
2. *Mitigating risk control* is where the risk control measure reduces the severity of the outcome of the event or subsequent events, should they occur.
3. *Passive risk control* is where there is no action required to deliver the risk control measure,
4. *Active risk control* is where the risk control is provided by the action of safety equipment or operators
5. *Critical human factors* are where human action is vital to control the risk either where failure of the human action will directly cause an accident or will allow an accident sequence to progress. Where a *critical human factor* attribute is assigned, the human action (or critical task) should be clearly defined in the risk control measure.

For each one of medium or high-risk scenarios the following tables are filled to assign the attributes for the selected RCM. This corresponds to Step 4 of the FSA (decision making).

Attributes of RCM				
Preventive: the RCM reduces the probability of the event.	Mitigating: the RCM reduces the severity of the outcome	Passive: no action is required to deliver the RCM	Active: action by safety equipment or operators is required	Critical human factor: human action is vital to control the risk
YES/NO	YES/NO	YES/NO	e.g. activate	YES/NO

Table 4: Second task for the experts - Assign attributes to selected RCMs

Task 3: Decision making - Evaluation of the RCM

In a third task the experts are asked to evaluate the suitability and effectiveness of the selected RCMs. According to the FSA Guidance this RCM evaluation is based on:

- Effectiveness: Will the RCM reduce risk significantly?
- Cost-efficiency: Is the RCM achievable at reasonable cost?
- Practicality: Is it feasible within vessel constraints?
- Robustness: Can it perform reliably under failure conditions?
- Sustainability: Is it maintainable over time?
- Side Effects: Does the RCM introduce new risks?
- Regulatory acceptance: Is the RCM accepted by Class?
- Auditability: Can the RCM be audited or not?

The effectiveness evaluation is based on the reduction of risk within the tolerable (ALARP) region, in accordance with the FSA guidelines. Specifically, it aims to demonstrate that a high-risk scenario can be reduced to a medium-risk level, and a medium-risk scenario within the tolerable region can be further lowered to the broadly acceptable (low-risk) region.

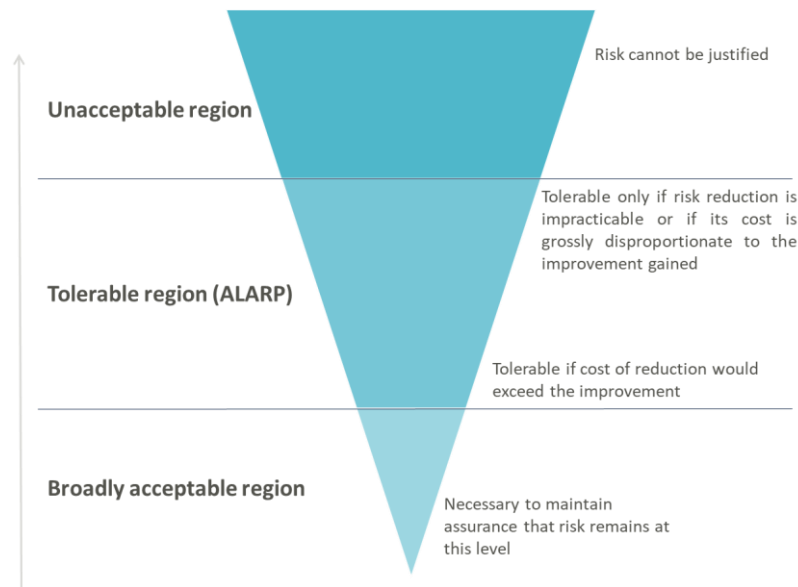


Figure 6: ALARP regions according to FSA Guidelines (source: RINA, adapted from MEPC.2/Circ.12/Rev.2)

The remaining aspects of evaluation of the RCM are conducted in a qualitative manner by the experts with responding (YES/NO) to the parameters of the evaluation. The last two aspects are subject to Class evaluation only.

RCM evaluation						
Cost-efficiency: Is the RCM achievable at reasonable cost?	Practicality: Is it feasible within vessel constraints?	Robustness: Can it perform reliably under failure conditions?	Sustainability: Is it maintainable over time?	Side Effects: Does the RCM introduce new risks?	Regulatory acceptance: Is the RCM accepted by Class?	Auditability: Can the RCM be audited?
YES/NO	YES/NO	YES/NO	YES/NO	YES/NO	YES/NO	YES/NO

Table 5: Third task for the experts - Evaluation of RCMs

5.6 Workshop session and Team

The workshop was prepared by RINA who send the material (excel files and preparatory documents with the context of work) to participants in advance. Three TEAMS meetings were organised by VARD Electro in July 2025.

The worksheets and tables used for recording the analysis have been projected in real time for agreement among all participants prior to recording.

The list of persons involved in the FSA workshop including observers and elaboration teams is given in the following table.

No.	Name	Company	Role
1	Stefanos Chatzinikolaou	RINA Hellas	Ass. Professor in Ship Technology, Maritime Risk Expert
2	Michael Markogiannis	RINA Hellas	Plan Approval Head
3	Murat Kurt	RINA Germany	Machinery & Safety Plan Approval Manager
4	Andreas Hjellbakk	VARD Electro	Research and Innovation Manager
5	Oeystein Longva	VARD Electro	Chief Technical Officer
6	Christian-Eric Bruzek	ASG	SMES Expert
7	Siim Kuunal	Skeleton	Supercapacitor Expert (Technical Grant Project Manager)

Table 6: Experts Group for FSA workshop

5.7 Results and Discussion

The results of the FSA workshop are included in Appendix 1: FSA workshop results for SMES and Appendix 2: FSA workshop results for SESS. The selected RCMs have successfully reduced the initial risk level from high to medium, or from medium to low, as requested by the FSA guidelines.

A number of hazards in SMES and SESS spreadsheets were introduced without recommended RCMs from the HAZID process. It was not possible to conduct the FSA for these hazards.

The attributes assignment has been concluded successfully by the experts for all RCMs. No disagreement was reported in the assignment of attributes.

The evaluation of suitability and effectiveness of RCMs has been conducted successfully for all selected RCMs. No disagreement was recorded among experts during the task. The RCMs evaluation shows that the selected RCMs are cost effective and practical.

A number of RCM may introduce additional risks which need to be further addressed.

The evaluation by Class showed that all RCMs can be accepted and are easy to check in audits and surveys.

5.8 FSA Conclusions

The FSA workshop successfully completed the Formal Safety Assessment process for the SMES and SESS installations onboard the Offshore Supply Vessel (OSV) within the V-ACCESS project framework. The expert group, representing classification, shipbuilding, and technology partners of the project, systematically identified, characterized, and evaluated Risk Control Measures (RCMs) for all Medium and High-risk scenarios derived from the earlier HAZID study.

The FSA workshop which took input from the HAZID work (risk assessment) concluded a risk management process for the two energy storage systems onboard the OSV vessel. Thereby, this work can serve as foundation for future studies that could support more demanding approval process such as for example the Technology Qualification process of Class.

It is highlighted that the approval process of new systems onboard must be conducted according to IMO on a case-by-case basis especially when the proposed design challenges the prescriptive statutory Rules (i.e. SOLAS). In such a case the IMO alternative design and arrangements (ADA) should be followed for the approval process. In the context of ADA, it will be needed a detailed description of the functional requirements of the design and a dedicated definition of the intended safety outcomes of the proposed design. New risk management studies should be conducted with the purpose to demonstrate that the proposed design (the ship with the energy systems installed) has equivalent or higher safety levels from the prescriptive SOLAS requirements.

6 Roadmap for integrating supercapacitors from Skeleton Technologies onboard electric vessels

Figure 2 in chapter 3.1 shows a roadmap for how Skeleton Technologies anticipate the TRL for their supercapacitors for the maritime market to develop. Figure 4 below shows a roadmap for integrating these supercapacitors onboard electric vessels. This roadmap is based on TRLs and technology/market development.

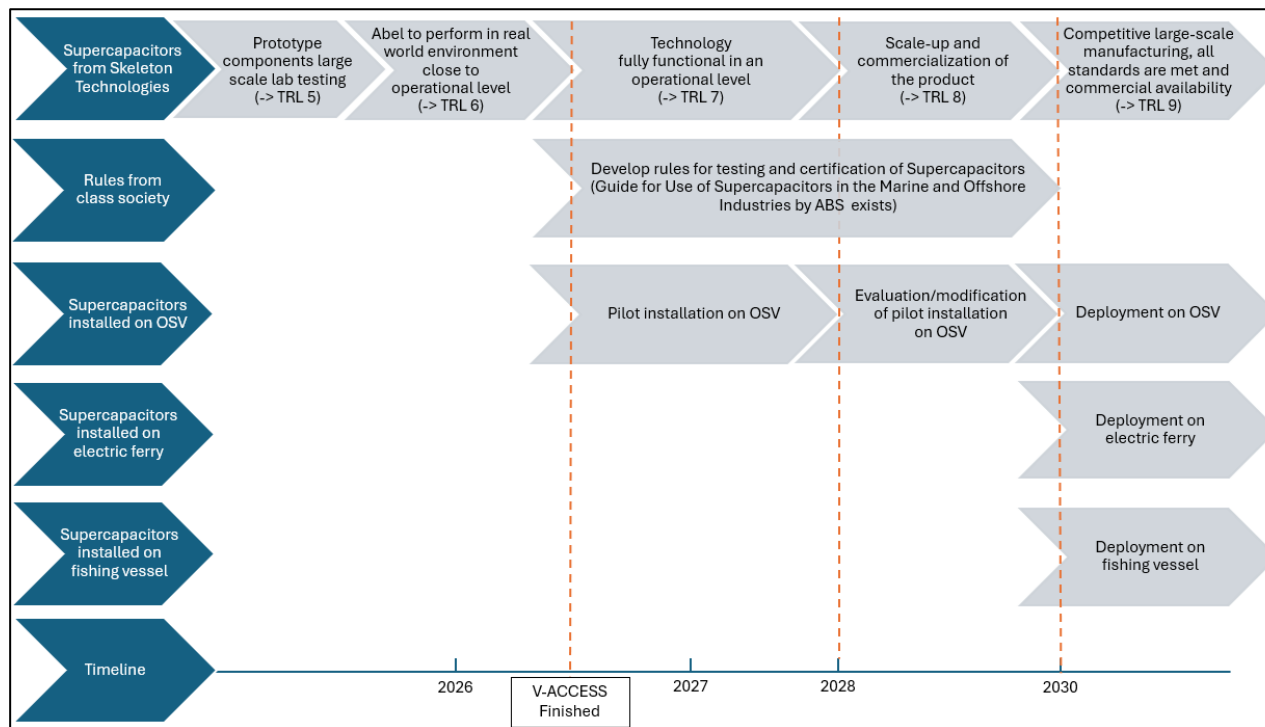


Figure 7: Roadmap for integrating supercapacitors from Skeleton Technologies onboard electric vessels

6.1 Technology demonstration (TRL 5-6)

TRL 5: Technology validated in relevant environment

According to the roadmap in Figure 2 the supercapacitors from Skeleton Technologies have been through large scale lab testing and have reached TRL 5 prior to the V-ACCESS project. The tests in the V-ACCESS project will anyhow validate the supercapacitors in a relevant environment and confirm the solution to be at least at TRL 5.

TRL 6: Technology demonstrated in a relevant environment

The tests in the V-ACCESS project will not make the supercapacitors able to perform in a real-world environment close to operational level but we know supercapacitors already have been installed on vessels. We will therefore state that the supercapacitors have reached TRL 6 outside the V-ACCESS project.

6.2 Market deployment (TRL 7-9)

TRL 7: System prototype demonstration in operational environment

To reach TRL 7 it is necessary to demonstrate the supercapacitor technology fully functional at an operational level. This should be carried out by installing the supercapacitors on a real vessel in a pilot project involving a supercapacitor manufacturer, a shipowner, a classification society and an electrical ship-systems integrator. In Figure 4 it is indicated that such *Pilot installation on OSV* project can start sometime after the V-ACCESS project is finished and will bring the supercapacitor solution up to TRL 7. It is difficult to estimate the duration of a pilot project but if the scope is limited to only demonstrate the supercapacitor technology on a vessel this should be possible within a year. If the pilot is started early in 2027 it should be finished early in 2028.

TRL 8: System completed and qualified

When TRL 7 is reached through a pilot project a period of evaluating the supercapacitor solution is needed. A process to scale up and commercialize the solution for the market will take place focusing on modifications to the solution to reach TRL 8. The length of this period depends on the cost and complexity of the necessary modifications to be made and the priority of these activities within the manufacturer organisation. To be able to qualify the solution and reach TRL 8 the rules and regulations need to be in place as well. When this will happen depends on the pace and priority in the actual authority organisations that produces the rules, but it should be possible to achieve some time in the period 2028-2030. When TR8 is reached the solution is ready for future deliveries on the type of vessel used in the pilot project (OSV).

TRL 9: System proven in operational environment

The next phase to reach TRL 9 contains challenges to create competitive large-scale manufacturing, meet all standards and make the supercapacitor solution commercially available for installation on vessels. In this phase considering installation on other vessel types than OSVs, e.g. electric ferries and fishing vessels, will take place. This may lead to amendments in rules and regulations and modifications in the supercapacitor solution to meet these changes. If TRL 8 is reached within 2030 this process will be ongoing from 2030 and ahead.

7 Roadmap for integrating SMES from ASG onboard electric vessels

Figure 3 in chapter 3.2 shows a roadmap for how ASG anticipate the TRL for their SMES for the maritime market to develop. Figure 5 below shows a roadmap for integrating SMES from ASG onboard electric vessels. This roadmap is based on TRLs and technology/market development.

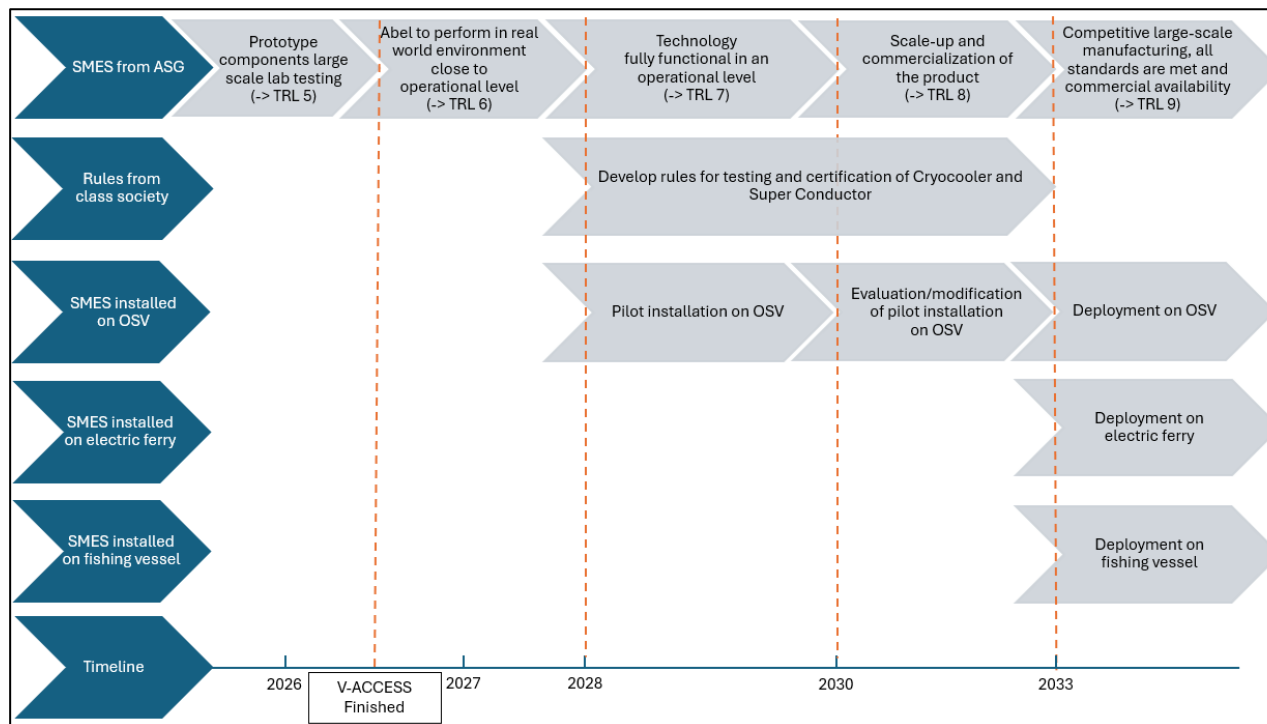


Figure 8: Roadmap for integrating SMES from ASG onboard electric vessels.

7.1 Technology demonstration (TRL 4-6)

TRL 4: Technology basic validation in a laboratory environment

According to the roadmap in Figure 3 Figure 2 a SMES prototype from ASG is demonstrated in the laboratory and considered to be on TRL 3-4 prior to the V-ACCESS project.

TRL 5: Technology validated in relevant environment

According to the roadmap in Figure 3 ASG foresee their SMES components to be large scale lab tested in the V-ACCESS project and reach TRL 5 at the beginning of 2026.

TRL 6: Technology demonstrated in a relevant environment

To reach TRL 6 it is necessary for the SMES to perform in real world environment close to operational level. Through test and design of mechanical support for vibrations and movements TRL 6 will be reached in 2028.

7.2 Market deployment (TRL 7-9)

TRL 7: System prototype demonstration in operational environment

To reach TRL 7 it is necessary to demonstrate the SMES technology fully functional at an operational level and should be carried out as a pilot project installing the SMES on a real vessel. To achieve this a protection chamber for environmental stresses needs to be designed and tested. A pilot project involving a supercapacitor manufacturer, a shipowner, a classification society and an electrical ship-systems integrator need to be setup. In Figure 5 below it is indicated that such *Pilot installation on OSV* project can take place from 2028 and will bring the SMES solution for vessels to TRL 7. It is difficult to estimate the duration of such pilot project. Because of new design and tests maybe 2 years will be sufficient, which means that TRL 7 can be reached in 2030.

TRL 8: System completed and qualified

When the SMES technology is demonstrated fully functional on a vessel in a pilot project and TRL 7 is reached a period of evaluating the SMES solution is needed. Testing of mechanical and environmental stresses will take place. A process to scale up and commercialize the solution for the market focusing on modifications to the solution to reach TRL 8 and create a complete and qualified system for future deliveries on vessels is needed. The length of this period depends on the cost and complexity of the necessary modifications to be made and the priority of these activities within the manufacturer organisation. To be able to qualify the solution and reach TRL 8 the rules and regulations need to be in place. When this will happen depends on the pace and priority in the actual authority organisations that produces the rules, but it should be possible to achieve this in the period 2030-2033. When TR8 is reached the solution is ready for future deliveries on the type of vessel used in the pilot project (OSV).

TRL 9: System proven in operational environment

The next phase to reach TRL 9 contains challenges to create competitive large-scale manufacturing, meet all standards and make the SMES solution commercially available for installation on vessels. In this phase considering installation on other vessel types than OSVs, e.g. electric ferries and fishing vessels, will take place. This may lead to amendments in rules and regulations and modifications in the SMES solution to meet these changes. If TRL 8 is reached within 2033 this process will be ongoing from 2033 and ahead.

8 Conclusions

- It is crucial to introduce a new technology as early as possible in the ship building process when it is going to be installed on a vessel. All parties - shipowner, shipbuilder, electrical system integrator, class society and manufacturer – need to be involved to make a success.
- The roadmaps from the manufacturer of the supercapacitors and SMES to be integrated must be synchronized with the activities needed for installation onboard a vessel.
- The results from the *Regulatory Coverage Gaps* and the *Technology Qualification Process (TQP)* activities are needed to be able to finally type approve the Supercapacitor and SMES systems for installation onboard vessels. In the meantime, in e.g. pilot projects, the Alternative Design process must be used.
- The FSA workshop successfully completed the Formal Safety Assessment process for the SMES and SESS installations onboard the Offshore Supply Vessel (OSV) within the V-ACCESS project framework. The expert group, representing classification, shipbuilding, and technology partners of the project, systematically identified, characterized, and evaluated Risk Control Measures (RCMs) for all Medium and High-risk scenarios derived from the earlier HAZID study.
- The roadmap for integrating supercapacitors from Skeleton Technologies in Figure 7 shows a pilot project started right after the V-ACCESS project is completed in 2026 using the Alternative Design process can bring the solution to TRL7 by 2028. If this is followed up by and evaluation/modification process and the necessary rules gap are filled TRL8 can be reached by 2030 and the large-scale roll-out of this solution on vessels can start.
- The roadmap for integrating SMES from ASG in Figure 8 shows an activity to make the SMES perform in a real-world environment close to operational level to start right after the V-ACCESS project is completed in 2026 can bring the solution to TRL6 by 2028. After this a pilot project can start to bring the SMES solution to TRL7 by 2030 using the Alternative Design process. If this is followed up by and evaluation/modification process and the necessary rules gap are filled TRL8 can be reached by 2033 and the large-scale roll-out of this solution on vessels can start.

References

- [1] Morandi A, Fabbri M, & al “Calculation of AC losses in a- 500 kJ /200 kW multifilamentary MgB2 SMES coil” Energies 2023 journal article DOI: 10.3390/en16041596.
- [2] J. Vialle, A. Badel, K. Takahashi, S. Awaji, P. Tixador “A High Performance Insulated REBCO Pancake With Conductive Cooling Capability » IEEE Transactions on Applied Superconductivity, vol. 33, 4600405, 2023.
- [3] J. Vialle, A. Badel, P. Tixador “12 T insulated REBCO magnet used as 1MJ SMES protection strategies and preliminary assembly test » IEEE Transactions on Applied Superconductivity, vol. 32, 4702307, 2022.
- [4] J. Vialle, A. Badel, P. Tixador, J. Cicéron, F. Forest, R. Pasquet “Preliminary Tests of Pancakes From a 12 T REBCO Insulated Solenoid Magnet” IEEE Transactions on Applied superconductivity, vol. 31, 4600805, 2021.
- [5] V-ACCESS “D5.4 Rules gap analysis”, RINA Germany, M. Kurt, C. Kutlar, 2025.

Appendix 1: FSA workshop results for SMES

FSA spreadsheet			V-Access		RINA	FSA attributes										FSA Evaluation of RCM									
Project		Node 1				Date										Attributes of RCM					RCM evaluation				
Category	HAZID Guideword	Top Event (Hazard Release)	Initial/Presumed Risk ranking	Existing Control/Mitigation Measures		Risk Control Measures	Comments	Risk	Preventive: RCM reduces the probability of the event.	Mitigating: the RCM reduces the severity of the outcome	Passive: no action required to deliver the RCM	Active: action by safety equipment or operators is required	Critical human factor: define the human action needed	Cost-efficiency: Is the RCO achievable at reasonable cost?	Practicality: Is it feasible within vessel constraints?	Robustness: Can it perform reliably under failure conditions?	Sustainability: Is it maintainable over time?	Side Effects: Does the RCO introduce new risks?	Regulatory acceptance: Is the RCO accepted by Class?	Auditability: Can the RCO be audited or not?					
1. Equipment	1.1 Equipment failures	Cryocooler failure	Medium	- High thermal insulation of the design	- Having two (2) cryocoolers for redundancy is recommended		Medium	Y	N/A	N	Y	N	Y	Y	Y	Y	N	Y	Y						
		Helium leakage (due to loss of mechanical integrity of cryocooler or compressor)	Medium	- Amount of Helium in the system is not enough to cause asphyxiation	- Using gas sensors to detect oxygen level in the compartment is recommended	- There are no specific exposure limits for Helium. Helium is a simple asphyxiant (SA). Oxygen levels should be maintained above 19.5%.	Low	Y	N	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y					
								- No helium storage tank connected to the system	- Using temperature sensors in the compartment is recommended	- Helium in the system is max. 1L, at 10 bar pressure	Low	Y	N	N	Y	Y	Y	Y	Y	Y	N	Y	Y		
												- Reinforced, double walled (for thermal insulation) flexible tubes are used in helium circuits. Fittings, etc. are of stainless steel.	Low	N	Y	Y	N	Y	N	Y	Y	Y	N	Y	Y
														- Installing flexible tubes within rigid pipes to mitigate the risk of mechanical damage is recommended	Low	Y	N	N	Y	Y	Y	Y	Y	N	Y
								- No helium storage tank connected to the system	- Operational manual to discharge the coil shall be prepared.	Medium		Y	Y	Y	Y	Y	Y	N	Y	Y					
		- Small amount of helium in the system	- No helium storage tank connected to the system	Medium	No RCM																				
		Low	No RCM																						

FSA spreadsheet			Project		RINA	FSA attributes													
Node 1			V-Access			FSA Evaluation of RCM													
Date			SMES (Superconductor Magnetic Energy Storage System) and Integration			Attributes of RCM						RCM evaluation							
Date			07.11.2025			Attributes of RCM						RCM evaluation							
Category	HAZID Guideword	Top Event (Hazard Release)	Initial/Presumed Risk ranking	Existing Control/Mitigation Measures	Risk Control Measures	Comments	Final/Reduced Risk ranking	Preventive: RCM reduces the probability of the event.	Mitigating: the RCM reduces the severity of the outcome	Passive: no action required to deliver the RCM	Active: action by safety equipment or operators is required	Critical human factor: define the human action needed	Cost-efficiency: Is the RCO achievable at reasonable cost?	Practicality: Is it feasible within vessel constraints?	Robustness: Can it perform reliably under failure conditions?	Sustainability: Is it maintainable over time?	Side Effects: Does the RCO introduce new risks?	Regulatory acceptance: Is the RCO accepted by Class?	Auditability: Can the RCO be audited or not?
		Magnet quenching	Medium	- Quench protection	- Placing the Protection Resistance in a stainless steel enclosure is recommended. - Maintenance of the Protection Resistance to be included in the Operation Manual of SMES.	- "Protection Resistance" is used for immediate (milliseconds to seconds) discharge of the coil, during which the resistance gets very hot, very quickly. High fire risk (with previous examples) if there's dust and/or oil accumulation of the resistance during the process.	Low	N	Y	Y	N	N/A	Y	Y	Y	Y	N	Y	Y
		Low					Y	N	N	Y	N/A	Y	Y	Y	Y	N	Y	Y	
	1.2 Control System failures	Loss of communication with PMS (Power Management System)	Medium		- The SMES system must be fitted with a manually activated emergency shutdown system adjacent to but outside the superconductor space. The emergency shutdown circuit is to be hardwired and independent of any control, monitoring, and alarm system circuits.	- Control, monitoring, and safety systems are to have the ability to self-monitor. In the event of failure to the systems or power supply, an alarm is to be activated.	Low	N	Y	N	Y	Activation	y	y	n	y	y	y	y
	Low	n			y	n	y	Activation	y	y	n	y	y	y					

Document name:	D4.4 Roadmap for integrating new storage units onboard electric vessels	Page:	36
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FSA spreadsheet			Project		RINA	FSA attributes													
Node 1			V-Access			Attributes of RCM						FSA Evaluation of RCM							
Date			07.11.2025			Attributes of RCM						RCM evaluation							
Category	HAZID Guideword	Top Event (Hazard Release)	Initial/Presumed Risk ranking	Existing Control/Mitigation Measures	Risk Control Measures	Comments	Final/Reduced Risk ranking	Preventive: RCM reduces the probability of the event.	Mitigating: the RCM reduces the severity of the outcome	Passive: no action required to deliver the RCM	Active: action by safety equipment or operators is required	Critical human factor: define the human action needed	Cost-efficiency: Is the RCO achievable at reasonable cost?	Practicality: Is it feasible within vessel constraints?	Robustness: Can it perform reliably under failure conditions?	Sustainability: Is it maintainable over time?	Side Effects: Does the RCO introduce new risks?	Regulatory acceptance: Is the RCO accepted by Class?	Auditability: Can the RCO be audited or not?
2. Location/Environment	2.1 Location Hazards	Fire from adjacent space	Medium	- Fixed fire detection and fighting systems	<ul style="list-style-type: none"> - Superconductor space is to be considered an Auxiliary Machinery Space or a Machinery Space other than Category A, as defined in SOLAS Reg. II-2. - It is recommended that there is no interconnection of the ventilation ducts between the compartment and the rest of the ship. - Having an emergency shutdown system for the compartment's ventilation, from a remote location is recommended. - Manual activation capability of fi-fi system from remote location is recommended - Usage of suitable fixed fire fighting systems for electrical fires is recommended. - Having a cofferdam compartment between supercapacitor space and Category A spaces (eg Engine Room) is recommended. 		Low	N	Y	Y	N	N/A	Y	Y	Y	Y	N	Y	Y
							Low	N	Y	Y	N	N/A	Y	Y	Y	Y	N	Y	Y
							Low	N	Y	N	Y	Activation	Y	Y	Y	Y	N	Y	Y
							Low	N	Y	N	Y	Activation	Y	Y	Y	N	Y	Y	
							Low	N	Y	N	Y	Activation	Y	Y	Y	Y	N	Y	Y
							Low	N	Y	N	N	N/A	Y	Y	Y	Y	N	Y	Y
	Fire from battery systems in the same space	- Fixed fire detection and fighting systems	<ul style="list-style-type: none"> - Not placing batteries and SMES in the same compartment is recommended (battery room to have AGO insulation) - Usage of suitable fixed fire fighting systems for electrical fires is recommended 	Supercapacitor spaces are not to contain any heat sources or high fire risk objects. (Batteries are considered high fire risk objects due to their potential for thermal	Low														
					Low	N	Y	N	Y	N/A	Y	Y	Y	N	Y	Y			

Document name:	D4.4 Roadmap for integrating new storage units onboard electric vessels	Page:	37
Dissemination	PU	Version	1.0

FSA spreadsheet			Project		RINA	FSA attributes										FSA Evaluation of RCM				
Node 1			V-Access			Attributes of RCM										RCM evaluation				
Date			SMES (Superconductor Magnetic Energy Storage System) and integration			Preventive: RCM reduces the probability of the event.										Cost-efficiency: Is the RCO achievable at reasonable cost?				
Category	HAZID Guideword	Top Event (Hazard Release)	Initial/Presumed Risk ranking	Existing Control/Mitigation Measures	Risk Control Measures	Comments	Final/Reduced Risk ranking	Preventive: RCM reduces the probability of the event.	Mitigating: the RCM reduces the severity of the outcome	Passive: no action required to deliver the RCM	Active: action by safety equipment or operators is required	Critical human factor: define the human action needed	Cost-efficiency: Is the RCO achievable at reasonable cost?	Practicality: Is it feasible within vessel constraints?	Robustness: Can it perform reliably under failure conditions?	Sustainability: Is it maintainable over time?	Side Effects: Does the RCO introduce new risks?	Regulatory acceptance: Is the RCO accepted by Class?	Auditability: Can the RCO be audited or not?	
5. Operating Modes	5.1 Operation of the Ship	Flooding of compartment	High Medium	- System to be stopped, and energy discharged to the resistance	No RCM		Low													
	6.1 Operation	SMES alarm failure	Medium	- Only a couple of seconds of delay in switching to backup power	- A manually activated emergency power switch system (hardwired and independent of any control, monitoring, and alarm system circuits) is recommended.	- In the event of an SMES failure, if the batteries are fully charged and the gangway continue regenerating energy the voltage on the Main Switchboard will increase.	Low	N	Y	N	Y	Activation	Y	Y	N	Y	Y	Y	Y	Y
6. Operation and Maintenance (of the system)	6.2 Maintenance	Improper handling	Medium	- Maintenance to be performed only by expert/authorized personnel on port.	- Placing warning labels informing the user of the dangers of working with the different parts of the SMES is recommended. - Fitting insulated handles and handrails for access around the SMES equipment is recommended.		Low	Y	N	Y	N	N/A	Y	Y	Y	Y	N	Y	Y	Y
		Dangerous maintenance	Medium		manual and PPE		Low	Y	N	N	N	N/A	Y	Y	Y	Y	N	Y	Y	Y
			High		external		Medium	Y	N	Y	Y	Y	Y	N (only in port)	Y	Y	N	Y	Y	Y

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Appendix 2: FSA workshop results for SESS

FSA spreadsheet																		
Project		V-Access																
Node 1		SESS (Supercapacitor Energy Storage System) and integration																
Date		7.11.2025																
Category	HAZID Guideword	Top Event (Hazard Release)	Initial Risk	Existing Control/Mitigation Measures	Recommended RCM	Risk	Attributes of RCM					RCM evaluation						
			Risk				Preventive: RCM reduces the probability of the event.	Mitigating: the RCM reduces the severity of the outcome	Passive: no action required to deliver the RCM	Active: action by safety equipment or operators is required	Critical human factor: define the human action needed	Cost-efficiency: Is the RCO achievable at reasonable cost?	Practicality: Is it feasible within vessel constraints?	Robustness: Can it perform reliably under failure conditions?	Sustainability: Is it maintainable over time?	Side Effects: Does the RCO introduce new risks?	Regulatory acceptance: Is the RCO accepted by Class?	Auditability: Can the RCO be audited?
1. Equipment	1.1 Equipment failures	Puncture/crush due to mechanical abuse or collision	Medium	- Mechanical ventilation in the compartment	- Maintaining negative pressure, with two (2) fans for redundancy, is recommended.	Low	N	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y
				- Vapour is expelled from the cabinet by the integrated cooling fan and dissipated in the compartment.	- Identification and calculation of max quantity of vapour release due to the puncture (worst case scenario) is recommended.	Low	Y	N	N	Y	Assessment	Y	Y	Y	Y	N	Y	Y
					- Running the cooling fan intermittently to dissipate any possible vapour is recommended.	Low	Y	Y	N	Y	Activate	Y	Y	Y	Y	N	Y	Y
	1.2 Control System failures	Loss of communication with PMS (Power Management System)	Medium	Safety testing done at the manufacturer facility	- It is recommended that SESS system is type approved	Low	Y	N	N	N	N	Y	Y	Y	Y	N	Y	Y
				- Cabinet has local control switch, from where you can manually activate discharge if needed		Low	N	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y
	Cell overvoltage	Medium	Overvoltage detection/protection	- Performing a fire propagation test is recommended.		Low	Y	N	Y	N	N	Y	Y	Y	Y	N	Y	Y
- Safety gas release valve per cell for pressure relief/venting (mechanical activation)				- Installing gas detectors for C2H3N (Acetonitrile) above the supercapacitor cabinets is recommended.	Low	Y	N	Y	N	N	Y	Y	Y	Y	N	Y	Y	

FSA spreadsheet																			
Project		V-Access																	
Node 1		SESS (Supercapacitor Energy Storage System) and integration																	
Date		7.112025																	
Category	HAZID Guideword	Top Event (Hazard Release)	Initial Risk	Existing Control/Mitigation Measures	Recommended RCM	Risk	Attributes of RCM					RCM evaluation							
			Risk				Preventive: RCM reduces the probability of the event.	Mitigating: the RCM reduces the severity of the outcome	Passive: no action required to deliver the RCM	Active: action by safety equipment or operators is required	Critical human factor: define the human action needed	Cost-efficiency: Is the RCO achievable at reasonable cost?	Practicality: Is it feasible within vessel constraints?	Robustness: Can it perform reliably under failure conditions?	Sustainability: Is it maintainable over time?	Side Effects: Does the RCO introduce new risks?	Regulatory acceptance: Is the RCO accepted by Class?	Auditability: Can the RCO be audited?	
1.3 Electrical system failures		Cell over-temperature	Medium	- Temperature monitoring system - Safety gas release valve per cell for pressure relief/venting (mechanical activation)	No RCM		Y	N	Y	N	N	Y	Y	Y	Y	N	Y	Y	
		Grounding failure	Medium	- Polymer casing (no need for protective earth)	No RCM														
		Undervoltage	Medium	- Undervoltage detection/protection	No RCM														
		Overcharging	Medium	- Overvoltage detection/protection - Pressure relief mechanism	Install eq for overvoltage detection/protection		Y	N	Y	N	N	Y	Y	Y	Y	N	Y	Y	
					- Supercapacitor space is to be considered an Auxiliary Machinery Space or a Machinery Space other than Category A, as defined in SOLAS Reg.11-2. - It is recommended that there is no interconnection of the ventilation ducts between the compartment and the rest of the ship.	Low													



V-ACCESS; Grant agreement ID: 101096831

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FSA spreadsheet																					
Project		V-Access																			
Node 1		SESS (Supercapacitor Energy Storage System) and integration																			
Date		7.11.2025																			
Category	HAZID Guideword	Top Event (Hazard Release)	Initial Risk	Existing Control/Mitigation Measures	Recommended RCM	Risk	Attributes of RCM					RCM evaluation									
			Risk				Preventive: RCM reduces the probability of the event.	Mitigating: the RCM reduces the severity of the outcome	Passive: no action required to deliver the RCM	Active: action by safety equipment or operators is required	Critical human factor: define the human action needed	Cost-efficiency: Is the RCO achievable at reasonable cost?	Practicality: Is it feasible within vessel constraints?	Robustness: Can it perform reliably under failure conditions?	Sustainability: Is it maintainable over time?	Side Effects: Does the RCO introduce new risks?	Regulatory acceptance: Is the RCO accepted by Class?	Auditability: Can the RCO be audited?			
2. Location/ Environment	2.1 Location Hazards	Fire from adjacent space	Medium	- Fixed fire detection and fighting systems	- Having an emergency shutdown system for the compartment's ventilation, from a remote location is recommended. - Manual activation capability of fi-fi system from remote location is recommended. - External fire fighting system with cooling capability, such as watermist or sprinkler system, is recommended. - Having a cofferdam compartment between supercapacitor space and Category A spaces (e.g Engine Room) is recommended.	Low	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	
		Fire from battery systems in the same space	High	- Fixed fire detection and fighting systems	- Not placing batteries and SMES in the same compartment is recommended (battery room to have A80 insulation)	Low	Y	N	Y	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	

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FSA spreadsheet																		
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		High humidity or saltwater exposure	Medium		- Supercapacitor cabinets having a degree of protection not lower than IP44 is recommended	Low	Y	N	Y	N	N	N	Y	Y	Y	N	Y	Y
		Exposure of electrolyte vapour inside supercapacitor cells	Medium	see 1.1 Equipment-failures		Low	Y	N	N	N	N	Y	Y	Y	Y	N	Y	Y
5. Operating Modes	5.1 Operation of the Ship	Flooding of compartment	Medium	- System to be stopped, and energy discharged		Low	Y	N	N	N	N	Y	Y	Y	Y	N	Y	Y
6. Operation and Maintenance (of the system)	6.1 Operation	SESS alarm	Medium	backup power	(hardwired and independent of any control, monitoring, and	Low	N	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y
	6.1 Operation	SESS shut down failure	Medium			Low	N	Y	N	Y	N/A	Y	Y	Y	Y	Y (oversee ala	Y	Y
		SESS emergency shut down	Medium		alarm system circuits) is recommended.	Low	N	Y	N	Y	N/A	Y	Y	Y	Y	Y (oversee ala	Y	Y
		ESS sudden shut down	Medium			Low	N	Y	N	Y	N/A	Y	Y	Y	Y	Y (oversee ala	Y	Y

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	6.2 Maintenance	Improper handling	Medium	performed only by expert/authorized personnel - Maintenance to start by grounding the system, i.e. no voltage	- Consider placing warning labels informing the user of the dangers of working with the different parts of the SESS.	Low	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	(human error)	Y	Y	
		Dangerous maintenance	High			Medium	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	(human error)	Y	Y	

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