Swappable Container Waterborne Transport Battery

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Reducing the Cost of Large Batteries for Waterborne Transport

D2.1

Design Recommendations Battery

1 April 2021

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GLOSSARY OF TERMS

Term	Definition
Alert	An alert consists of a Warning, Alarm, or Fault
Battery System	The highest-level building block within the energy storage system
BMS	Battery management system
Building Block	An arbitrarily sized electrical or physical unit of the system. There can be multiple tiers of building blocks nested in one another.
Cell group	Group of paralleled cells
EaaS	Energy as a Service
Electrical Building Block	An arbitrarily sized standalone electrical component in the system. There can be multiple tiers of electrical building blocks nested within each other.
EMS	Energy management system
FiFi	Firefighting
Installation Unit	The building block used during installation
LRU	Line Replaceable Unit.
Mechanical Building Block	An arbitrarily sized, standalone mechanical component in the system. There can be multiple tiers of mechanical building blocks nested within each other.
OEM	Original Equipment Manufacture
PCS	Power Conversion System
PMS	Power management system
Service Unit	The building block that can be serviced in the field
SOC	State of charge
SOH	State of health
String	Number of serialized cell groups operating at battery system voltage
System Bus	Communication bus from the battery system to the customer / EMS.

DOCUMENT PROPERTIES

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PROJECT SUMMARY

Current Direct, a new research and innovation project funded by the European Commission's Horizon 2020 program, will revolutionize the way we move goods and people by water. The vast majority of water transport in Europe is propelled by dirty, noisy diesel engines. By cutting the cost of today's marine battery electric drivetrains in half and relieving ship owners of the burden of capital expense, Current Direct will enable rapid adoption to reduce greenhouse emissions.

Current Direct's innovative Energy as a Service platform will enable ship owners to accelerate their participation in the shift to clean energy while creating new business opportunities for shipyards and local entrepreneurs. By changing the model for acquiring and storing energy aboard vessels, Current Direct will create a new energy economy, adding thousands of new jobs. Current Direct provides a vehicle for energy companies, institutional investors, and government stakeholders to participate in the green transformation of Europe's merchant and passenger fleet.

Current Direct brings together thirteen dynamic partners from across Europe's marine electrification value chain. The project is led by Spear Power Systems, makers of the world's lightest, most flexible marine batteries certified to the most stringent international safety standards. Blackstone Technology is lowering the cost of manufacturing tomorrow's 3D printed lithium-ion cells using state of the art active materials from Umicore. The University of Hasselt will use its electrochemical expertise to develop physics-based models of the Current Direct cells that will help optimize the life and return on investment of battery systems deployed across Europe as part of the Current Direct Energy as a Service platform developed by the accomplished engineers and data scientists at Rhoé Urban Technologies and Aviloo. Naval architecture and marine engineering company Foreship will lend its expertise to EDP CNET's in depth knowledge of electrical markets to ensure the Current Direct platform targets optimal vessels and locations maximizing reductions in emissions. VUB's material science experts are creating low-cost composites to improve the safety of battery packs that are designed for recyclability and feature VITO's smart cell monitoring electronics. Wärtsilä will develop modular battery containers and charging infrastructure that will be certified to innovative standards developed together with Lloyd's Register. The project will culminate in a demonstration of the Current Direct battery, shore charging, and asset management platform by Kotug in Rotterdam.

The Current Direct EcoSystem is shown in Figure 1.

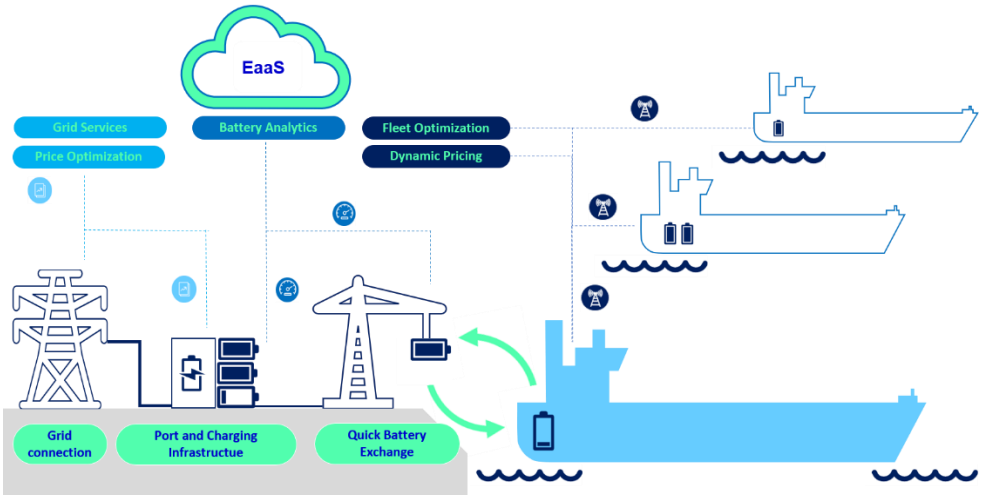

Figure 1. Current Direct EcoSystem

1. SPECIFIC OBJECTIVES FOR WORK PACKAGE 2

1.1. Introduction

This WP will define the requirements for the two Current Direct technology pillars: the Waterborne Transport Battery and the EaaS platform. This WP will also assess the current state of the Waterborne Transport market to provide inputs for WP6 regarding classification societies, national maritime authorities, independent standards bodies, and de facto commercial standards. It will synthesize the power and energy requirements, operating profiles, and installed propulsion topologies of various vessel types across Europe's inland waterways and coastal shipping routes. While this work package will generate deliverables D2.1, D2.2 and D2.3 in month M3 to provide a solid baseline for the Phase II Development work, the requirements and specifications will be updated throughout the Development phase until the tasks they feed into reach a design freeze.

Specific Objectives:

- Identify and engage relevant stakeholders to define market technical and financial needs
- Define operational requirements for the Waterborne Battery & supporting vessel infrastructure
- Define business requirements for the EaaS platform
- Define the current state of certification and regulatory frameworks for waterborne transport batteries and analyze opportunities for standardization
- Assess current vessel integration and port electrical infrastructure for battery charging
- Specify design requirements to maximize recyclability of the Current Direct solutions

1.2. Capture Methodology Introduction and Description

The owner for work package 2 is Foreship. For gathering information and requirements, a kick-off meeting was held with all the consortium members on January 15th, 2021. The process and the methodology were described and agreed during the meeting. The workflow, time schedule and Owners of the different sub-categories was communicated. The common platform for gathering the requirements is Box. Revision handling of documents are done in Box, using a manual methodology.

The main principles of the process for gathering requirements are described in Figure 2.

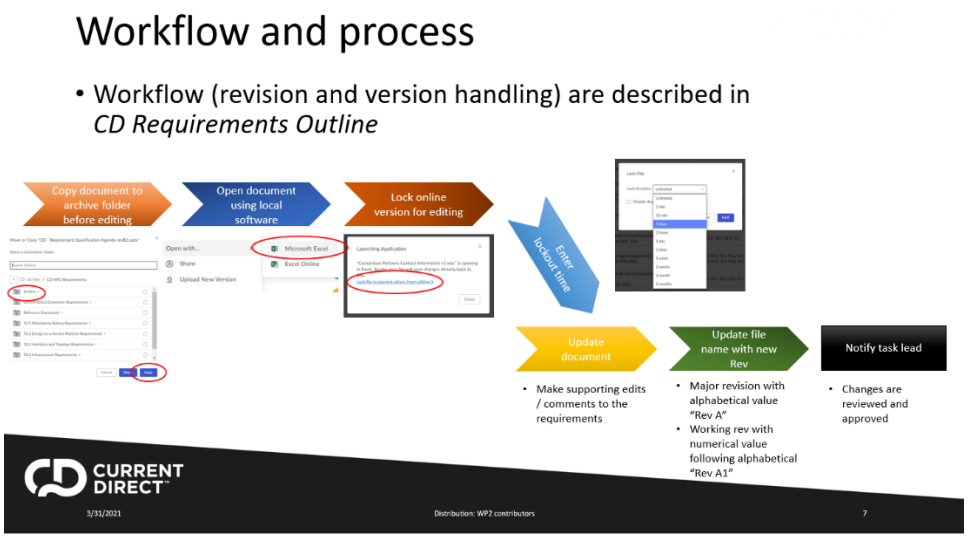

Figure 2. Workflow and Process for Gathering Requirements

1.3. Requirement Structure and Information Gathering Principles

1.3.1. Current Direct Requirements Structure Outline Document Description

This document outlines Current Direct's requirements hierarchy, document lead, content descriptions, file locations, member access rights, and editing rule. The document is saved under the common folder available to all members.

1.3.2. Technical and Financial Requirements

The requirements are broken up into two categories: technical requirements, and financial requirements. Technical requirements are saved at the file locations indicated in the Requirements Hierarchy section below. Financial requirements are located in the member's folder providing the component or service so financial privacy can be maintained.

1.4. Requirements Hierarchy and Relationship

Figure 3 below outlines Current Direct's requirements hierarchy. The Ecosystem is the highest-level document from which all other requirements are derived from.

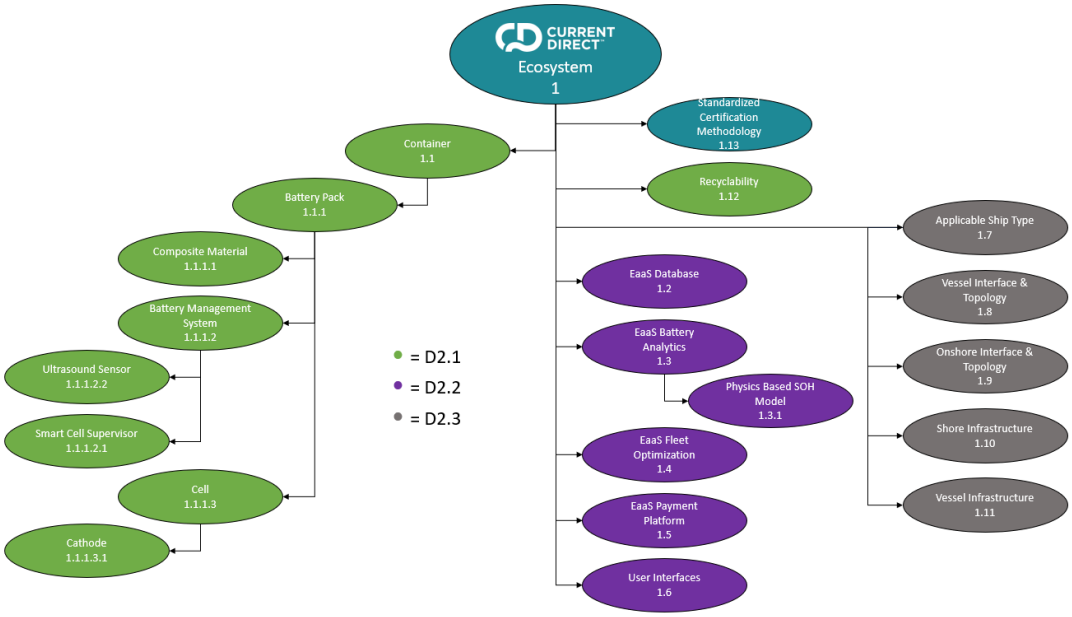

Figure 3. Requirements Hierarchy

Requirement documents are also related to one another independent of the serial hierarchy. This means that a requirement document in one branch of the system can driver or refer to one from a separate branch. An example would be the container interfaces which determine aspects of both the vessel and onshore systems.

2. ECOSYSTEM KPI'S

2.1. Introduction

Current Direct KPI and lifecycle considerations are gathered in a separate document called Ecosystem requirement, where KPI's are described. The Ecosystem KPI's are presented in Table 1.

Table 1. Ecosystem KPI's

Requirement Category	Description	KPI ID [A]	Target
Key Performance Indicators	Cost Reduction	A1.1.1	20% cost reduction over current commercial marine cells at volume production
		A1.1.2	Achieve ≥12,000 cycles at 70% Depth of Discharge before reaching 70% State of Health.
		A1.1.3	Cost 500 €/kWh for the waterborne transport battery container.
		A1.1.4	Have a cost per unit energy throughput 1/2 that compared to today's waterborne battery transport battery systems.
		A1.1.5	Have an OPEX ≤ compared to conventional diesel fuel.
	Increased Energy	A1.2.1	Cell level density ≥500 Wh/L
		A1.2.2	Pack level energy density ≥200 Wh/L
		A1.2.3	Have an installed capacity ≥ 2MWh in a 20' container.
	Environmental	A1.3.1	Reduce GHG emissions ≥1.5MT per discharge cycles when compared to tradition diesel propulsion.
		A1.3.2	Have ≥90% of the total waterborne battery container mass can be recycles
		A1.3.3	Reduce recycling processing cost by 30% when compared to today's containerized waterborne transport battery systems
	Market Acceleration	A1.4.1	Have a State of Health uncertainty of ≤2%
		A1.4.2	Accommodate ≥15% of today's and ≥85% of tomorrow's inland waterway and coastal shipping vessels
		A1.4.3	Support a container swap in ≤5 minutes
		A1.4.4	Have an EaaS operating cost ≤ the operating cost of diesel propulsion
		A1.4.5	Develop standardized certification methodology for marine battery systems.
		A1.4.6	Develop standardized certification methodology for vessels which adopt containerized energy storage systems through Current Direct's ecosystem.
		A1.4.7	Reduce battery system approval time by 30%
		A1.4.8	Reduce battery system approval cost by 75%
		A1.4.9	Be scalable to ≥ 6,000 users.
		A1.4.10	Be capable of supporting ≥ 23,000 deployed containers.

Requirement Category	Description	KPI ID [A]	Target
	Project	A1.5.1	Demonstrate the Current Direct Energy-as-a-Service platform through simulation
		A1.5.2	Establish a working demonstrator ecosystem featuring a waterborne battery container, supporting infrastructure, and the EaaS platform to a vessel in operation
		A1.5.3	Develop a demonstrator ecosystem with Technology Readiness Level (TRL) 7.
		A1.5.4	Create a demonstrator report every 3 months of operation
		A1.5.5	Create 1 Product Brochure
		A1.5.6	Create ≥ 3 Press Releases
		A1.5.7	Host ≥ 2 International Presentations
		A1.5.8	Host ≥ 1 Workshop

3. DESIGN RECOMMENDATION AND REQUIREMENTS

3.1. General

Design Recommendations for the Current Direct Waterborne Transport Battery will clearly describe verifiable, independent performance, safety, and cost requirements. Certain requirements will be specified as Performance Indicators (PIs). The requirements will synthesize inputs from suppliers, operators, classification societies, governments, and recyclers. They are the output of T2.1 and T2.5.

Design requirements shall also be considered according to both the demonstration unit and the wider commercialization beyond the end of the funded project.

3.1.1. Requirement Definition

Requirements are divided by category, identifier, description, type, and target.

- Requirement category - Category name for organization only (i.e., Physical Characteristics
- Requirement ID – Unique identifier for each requirement. ID do not change once assigned. Each requirement document has its own unique ID which prevents requirement ID's being duplicated used across documents.
- Description - Requirement description for organization only (i.e., Size).
- Type – There are three different types of requirements
- Reference; information only
- Shall; product must comply
- Should; compliance is preferred, but not required
- Target – Pass / Fail limits where applicable, design constraints, design standards

3.2. T2.1 Analysis and Specification of the Waterborne Battery

Lead: Spear; Contributors: Foreship, Wärtsilä, Lloyd’s, EDP, Blackstone, Umicore

This task will use the input collected through engagement in T9.3 with stakeholders throughout the Waterborne Battery value chain including governments who award routes, ship owners, naval architects, shipyards, ports, electrical integrators, classification societies, national maritime authorities, and fire fighters to develop a comprehensive set of technical requirements for the Current Direct battery. Requirements D2.1 will be synthesized and refined to provide a set of design specifications for WP3 and WP4. As the project progresses the requirements will be updated based on lessons learned and continued stakeholder input. Many requirements gathered in this task will feed WP7 including power and mechanical interfaces of the battery container to the ship and shoreside infrastructure (T7.1, T2.3, and T2.4), communications interfaces to the ship and shore (T7.2), and safety and performance standards (T7.3, T7.4). Moreover, a set of performance PIs will be defined that constitutes a demonstration framework against which the operational performance of the battery container will be evaluated against during the demonstration activities in WP6 (T6.1 and T6.6). The gathered PIs will further serve as a base for the validation of the business case in WP8 (T8.3).

3.2.1. Container (1.1)

Requirement for the container are presented in Table 2.

Table 2. Container

Requirement Category	Description	Requirement ID [B]	Type	Target
General Information	Objective	B1.2.1	Reference	To develop a fully independent containerized energy storage system with a standard 20' ISO envelope.
Physical Characteristics	Weight	B4.1.1	Shall	Weigh ≤25000 kg
	Size	B4.2.1	Shall	Be designed according to ISO 20' container dimensional standards
		B4.2.2	Should	Be designed according to ISO 20' high cube container dimensional standards
Functional Behavior	Battery Capacity	B5.1.1	Shall	Contain battery capacity of ≥2MWh
	Onboard Charging	B5.4.1	Should	Support independent onboard charging from shore power while installed on a vessel
Safety	Emergency Stop	B6.3.1	Shall	Include an externally hardwired mordancy stop interface
		B6.3.2	Shall	An independent emergency stop external of the container
	Exhaust Vent	B6.4.1	Shall	Have dedicated ventilation exhaust system for ESS
		B6.4.2	Shall	Be activated upon detection of Fire / Smoke in the battery compartment or thermal runaway gas detection.
	Fifi System - Internal	B6.5.1	Shall	Include Fifi system
		B6.5.2	Shall	FiFi system to be self-contained & independent from vessel / shore infrastructure
	Fifi System - External	B6.6.1	Should	Support external fifi system if deployed
	Fire/Smoke Detection	B6.7.1	Shall	Incorporate fire / smoke detection system.
		B6.7.2	Shall	Be independent from vessel / shore
		B6.7.4	Shall	Communicate status of the fire / smoke detection system to the vessel
		B6.7.5	Shall	Comply to FSS-code
	Gas Detection	B6.8.1	Shall	Incorporate gas detection system to detect a thermal runaway event.

Requirement Category	Description	Requirement ID [B]	Type	Target
		B6.8.4	Shall	Communicate status of the gas detection system to the vessel
		B6.8.5	Shall	Position detectors to give responsive of a detection of gas release.
		B6.8.6	Shall	Be independent from vessel / shore
		B6.8.7	Shall	Equipment in ESS space not suitable for hazardous area installation shall be shut down if gas is detected
	Temperature Monitoring	B6.9.1	Shall	Be monitored independent from battery system
	Door Monitoring	B6.11.1	Shall	Doors / hatches into container shall be monitored
Structure	Fire Class	B7.1.1	Shall	Maintain structural design integrity during thermal runaway event
	Structural Integrity	B7.2.1	Shall	Strength to be minimum according to ISO 1496-1 standards for containers
Electrical System	Cables	B8.3.1	Shall	Have current carrying capacity per IEC 60092-352
		B8.3.2	Should	Have minimum banding radius per IEC 60092-352
		B8.3.3	Shall	Have minimum bending radius to be as per manufacturers recommendations
		B8.3.4	Shall	Have cables suitable for hazardous area for all equipment powered after activation of gas detection system
		B8.3.5	Shall	Have installation per relevant rules / regulations and IEC 60092-352
	UPS	B8.4.1	Shall	Have UPS to be installed for auxiliary power supply.
		B8.4.4	Should	Be in separate space from ESS
		B8.4.5	Shall	Provide UPS status to telematics system.
	Distribution Board	B8.8.1	Should	Have breakers for auxiliary power
		B8.8.2	Should	Have breakers easily accessible
	External Auxiliary Power Supply	B8.9.1	Should	Have external power supply for auxiliary equipment during long term storage

Requirement Category	Description	Requirement ID [B]	Type	Target
	IECex / ATEX	B8.10.1	Shall	Equipment in ESS space that will remain switched on after detection of gas shall have suitable Ex-certification.
		B8.10.2	Shall	All equipment located at ceiling level in the EES space shall be s uitable for zone 2 installation.
		B8.10.3	Shall	Temperature class and gas grou p for the ex rated zone 2 equip ment shall as minimum be T2 a nd IIC.
		B8.10.4	Shall	Meet IEC 60079
Electrical Interfaces	Power Connection	B9.1.1	Shall	Be designed to minimize the need for human interaction
		B9.1.2	Shall	Have galvanic power connection
		B9.1.5	Shall	Allow for defined container movement
		B9.1.6	Should	Allow stacked containers to be electrically connected in parallel
		B9.1.7	Should	Allow stacked containers to be electrically connected independently
Mechanical Interfaces	Locking Connections	B10.1.1	Shall	Support mechanically swapping the container within 5mins
		B10.1.2	Should	Be self-locating
		B10.1.5	Shall	Be designed to minimize the need for human interaction
		B10.1.6	Shall	Minimize container movement
		B10.1.7	Shall	Allow containers to be securing stacked
		B10.1.8	Shall	Allow the container to be lifted
Communication Interfaces	Antennas	B11.1.1	Shall	Include a GSM antenna
		B11.1.2	Shall	Include a GPS antenna
		B11.1.3	Shall	Include a wifi antenna
	Communication Connection	B11.2.1	Shall	Be designed to minimize the need for human interaction
		B11.2.2	Shall	Have galvanic power connection
		B11.2.5	Shall	Allow for defined container movement
		B11.2.6	Should	Allow stacked containers to be electrically connected in parallel
		B11.2.7	Should	Allow stacked containers to be electrically connected independently.

Requirement Category	Description	Requirement ID [B]	Type	Target
Hvac	Temperature Regulation	B14.1.1	Shall	Be capable of controlling the temperature of the container per operating mode specifications in all operating environment conditions.
	Humidity	B14.9.1	Shall	Be capable of controlling the humidity of the container per operating mode specifications in all operating environment conditions.
	Thermal Insulation	B14.10.1	Shall	Container shall be sufficiently thermally insulated to support all operating mode specifications in all operating environment conditions
Service	Service Access	B16.1.1	Shall	Service access to be provided for equipment inside container
Reliability	Useful Life	B17.1.1	Shall	Support 20-year life
		B17.1.2	Should	Support 40-year life
	Storage Life	B17.2.1	Shall	Support 20-year life
		B17.2.2	Should	Support 40-year life

3.2.2. Battery Pack (1.1.1)

Requirement for Battery Pack are presented in Table 3.

Table 3. Battery Pack

Requirement Category	Description	Requirement ID [C]	Type	Target
General Information	Objective	C1.2.1	Reference	The development of an energy focused battery system with the goal for reducing costs and maximizing the amount of energy contained within a 20' shipping container.
Regulatory Certifications	Class Societies	C3.1.9	Shall	IACS
	Flag State	C3.2.1	Shall	NMA
		C3.2.3	Should	UK Maritime & Coastguard Agency
	Other Regulatory Certifications	C3.3.1	Shall	UN DOT 38.3
		C3.3.2	Shall	RoHS ES-TRIN
Physical Characteristics	Size	C4.1.7	Shall	Installation units can be installed in divisible units with less than 10% unused space in a 5898mm long container.

Requirement Category	Description	Requirement ID [C]	Type	Target
		C4.1.8	Should	Installation units can be installed in divisible units with less than 5% unused space in a 5898mm long container.
		C4.1.9	Shall	Installation units can be installed in divisible units with less than 10% unused space in a 2352mm wide container.
		C4.1.10	Should	Installation units can be installed in divisible units with less than 5% unused space in a 2352mm wide container.
		C4.1.11	Shall	Installation units can be installed in divisible units with less than 10% unused space in a 2591mm tall container.
		C4.1.12	Should	Installation units can be installed in divisible units with less than 5% unused space in a 2591mm tall container.
Connectors and Cables	External Connectors	C5.1.3	Shall	The main power connectors shall have an integrated safety interlock (HVIL), securing that connection/disconnection only can be performed when the battery contactor is open.
		C5.1.17	Shall	Unmated IP rating achieves at least IP44
		C5.1.19	Shall	Mated IP rating achieves at least IP44
	External Cables	C5.2.1	Shall	Support maximum operational charge/discharge currents at maximum operating temperature.
	Wire Routing	C5.3.1	Shall	Route and secure all wire harnesses safely per IEC standard 61914.
Performance	Maximum Battery Charge Voltage	C6.1.1	Shall	Support up to 1100 VDC
		C6.1.2	Should	Support up to 1250 VDC
	Energy Density	C6.5.1	Shall	System level energy density of ≥ 176 Wh/L
		C6.5.2	Should	System level energy density of ≥ 200 Wh/L
	Ingress Protection	C6.11.1	Shall	Prevent an arc under max voltage when subjected to spray conditions IPX4 for these water, glycol, and salt water.

Requirement Category	Description	Requirement ID [C]	Type	Target
		C6.11.2	Should	Prevent an arc under max voltage when subjected to spray conditions IPX6 for these water, glycol, and salt water.
		C6.11.3	Shall	Prevent an arc under max voltage when subjected to dust conditions IP4X.
		C6.11.4	Should	Prevent an arc under max voltage when subjected to dust conditions IP5X.
Functional Behavior	BMS	C7.1.1	Shall	Have an integrated BMS
Safety	Venting	C8.1.1	Shall	The ventilation of a cell pre- or post-thermal event shall not result in an explosion
		C8.1.2	Shall	Include a method to evacuate the gasses exterior of the vessel / container.
		C8.1.3	Shall	Be designed to minimize vented gas leakage into the battery compartment.
	Switch Disconnect	C8.4.1	Shall	The battery system's main power contactors or circuit-breakers shall disconnect both poles.
	Creepage and Clearance	C8.6.1	Shall	Pass creepage and clearance for 3820 VDC; Pollution Degree 3.
		C8.6.2	Should	Pass creepage and clearance for 3820 VDC; Pollution Degree 4.
	Coolant Leak	C8.9.1	Shall	Battery modules shall be designed such that the risk of a cooling liquid leakage inside the module is minimized and do not lead to hazardous creepage currents, electrolysis, short circuit, electric arcing, earth faults or other hazards.
		C8.9.2	Shall	Leakage detection inside the module shall be arranged if there is liquid cooling inside the module.

Requirement Category	Description	Requirement ID [C]	Type	Target
		C8.9.3	Shall	Battery systems shall be designed such that the risk of cooling liquid leakage in the battery system is minimized and do not lead to hazardous creeping currents, electrolysis, short circuit, electric arcing, earth faults or other hazards.
		C8.9.4	Shall	Leakage detection shall be arranged if liquid coolant is used.
	Cell Support	C8.11.1	Shall	Use cells which have passed IEC 62619
		C8.11.2	Shall	Use cells that meet UL 1642
		C8.11.3	Shall	Use cells which have passed UN DOT 38.3
	Pressure Relief	C8.12.1	Shall	For sealed batteries, a safety pressure valve or other means of explosion protection (weak point) shall be included in the battery design.
	E-Stop	C8.14.1	Shall	The battery system shall be equipped with an independent emergency shutdown for disconnection of the battery system.
Isolation	Shield Isolation	C9.1.1	Shall	All signal and control power cable shielding shall maintain 750VDC of isolation from the chassis with a minimum insulation resistance of 2.2MΩ.
	High Voltage Insulation Resistance	C9.2.1	Shall	Support >= 2.25 MΩ at 3820V for 1 min on each terminal, Modules and SCU
	High Voltage Dielectric Breakdown Voltage	C9.3.1	Shall	Support > 3820 VDC
		C9.3.3	Shall	Support > 6500VAC
	Signal/Control Voltage Insulation Resistance	C9.4.1	Shall	Support >= 1 MΩ at 707V for 1 min between all signal and control power nets and chassis
	DC Signal/Control Voltage Dielectric Breakdown Voltage	C9.5.1	Shall	Support > 707 VDC for 12-60V control power circuits

Requirement Category	Description	Requirement ID [C]	Type	Target
	AC Signal/Control Voltage Dielectric Breakdown Voltage	C9.6.1	Shall	Support 1500VAC or 2120VDC for 60-300VAC/VDC control power circuits
Testing Requirements	Drop Test	C10.1.1	Shall	Drop full module on its edge and corner from 5cm height with no fire or explosion.
	Altitude	C10.2.1	Shall	UN DOT 38.3, T.1 - Altitude Simulation
	Thermal Shock	C10.3.1	Shall	UN DOT 38.3, T.2 - Thermal Test
	Vibration	C10.4.1	Shall	UN DOT 38.3, T.3 - Vibration
	Shock / Impact	C10.5.1	Shall	UN DOT 38.4, T.4 - Shock
	External Short Circuit Test	C10.6.1	Shall	UN DOT 38.3, T.5 - External Short Circuit
	Overcharge	C10.8.1	Shall	UN DOT 38.3, T.7 - Overcharge
		C10.8.2	Shall	Overcharge with voltage per IEC 62619 8.2.2
		C10.8.3	Shall	Overcharge with current per IEC 62619 8.2.3
	Propagation Test	C10.10.2	Shall	Module to module thermal propagation protection
		C10.10.3	Should	Cell group to cell group thermal propagation protection
	Functional Performance Test	C10.11.1	Shall	Demonstrate all functions
	Electrical Power Supply Failure Test	C10.12.1	Shall	Experience at least 3 interruptions in 5 minutes with no permanent or temporary malfunctions.
	Power Supply variation Test	C10.13.1	Shall	Comply with class requirements
	Vibration Test	C10.14.1	Shall	Comply with class requirements
	Dry Heat Test	C10.15.1	Shall	70 ± 2°C for 16 hours, 50% RH
	Damp Heat	C10.16.1	Shall	80-100% relative humidity cycle, 22-57°C, pass hi-pot test within 1 hour
		C10.16.2	Shall	95% relative humidity, 55°C, 2 cycles of 12+12 hours
	Cold Test	C10.17.2	Shall	-25°C / 2 hours
	Ingress Protection Test	C10.22.1	Shall	Test to designed IP rating of the system per IEC 60529.

Requirement Category	Description	Requirement ID [C]	Type	Target
	Overheating	C10.26.1	Shall	Test overheating control per IEC 62619 8.2.4
	Sensor Failures	C10.27.1	Shall	Test detection of all failure modes of the sensors
	Function and Failure Response Testing	C10.30.1	Shall	Test normal operation and failure response of the BMS
	Independent Safety Function Test	C10.31.1	Shall	Test emergency disconnection function
		C10.31.2	Shall	Test independent temperature and or voltage-based disconnection
		C10.31.3	Shall	Test HVIL
	Dielectric Strength	C10.32.1	Shall	Comply with class requirements
	Pressure Test of Coolant Piping	C10.34.1	Shall	Comply with class requirements
Noise Immunity	EMC/EMI/ESD	C11.1.1	Shall	Comply with class requirements
Operating Environment Conditions	Discharge Ambient Temperature Range	C12.1.1	Shall	0 to 45 °C
		C12.1.2	Should	-25 to 55 °C
	Charge Ambient Temperature Range	C12.2.1	Shall	0 to 45 °C
		C12.2.2	Should	-25 to 55 °C
	Standby Ambient Temperature Range	C12.3.1	Shall	-25 to 55 °C
	Humidity	C12.5.1	Shall	≤ 96% RH
		C12.5.2	Should	≤ 100% RH
Material Selection	Asbestos Declaration	C13.1.1	Shall	Be 100% free of asbestos.
	Flammability	C13.2.1	Shall	The battery system shall be made of a flame-retardant material according to IEC 60092-101.
	Lead	C13.4.1	Shall	Shall meet ROHS standard
	Material Restrictions	C13.6.1	Shall	Meet ECHA regulations.
Reliability	Useful Life	C14.1.1	Shall	Support 10-year life
		C14.1.2	Should	Support 20-year life

Requirement Category	Description	Requirement ID [C]	Type	Target
	Shelf Life	C14.2.1	Shall	Support 10-year life
		C14.2.2	Should	Support 20-year life
Labeling	Product Identification	C17.1.1	Shall	Include markings that identify the product including part number, serial number, service contact information
	Warning/Hazard	C17.3.1	Shall	Include appropriate warning / hazard markings

3.2.3. Composite Material (1.1.1.1)

Requirements for composite material are presented Table 4.

Table 4. Composite Material

Requirement Category	Description	Category ID [D]	Type	Target
General Information	Objective	D1.2.1	Reference	To develop a novel material that combines properties of multiple components used in today's state of the art marine battery systems. This newly created composite will simplify the design and reduce both material and assembly costs.
Physical Characteristics	Mounting Features	D4.6.1	Shall	Incorporate features to allow for alignment with adjacent cell frames
Performance	Thermometric Properties	D5.5.1	Shall	Maintain all required material properties with up to 700°C surface temperature.
Reliability	Useful Life	D9.1.1	Shall	Support 10-year life
		D9.1.2	Should	Support 20-year life
	Shelf Life	D9.2.1	Shall	Support 10-year life
		D9.2.2	Should	Support 20-year life

3.2.4. Battery Management System (1.1.1.2)

Requirement for battery management system are presented in Table 5.

Table 5. Battery Management System

Requirement Category	Description	Requirement ID [E]	Type	Target
General Information	Objective	E1.2.1	Reference	The development of a battery management system to protecting the battery from operating outside a safe operating window and calculating / reporting data with the goal for reducing cost and maximizing the amount of energy contained within a 20' shipping container.
Performance	State of Charge	E4.1.1	Shall	Estimate and provide the battery's State of Charge (SOC)
		E4.1.3	Shall	Provide accurate SOC prediction within ± 5%.
		E4.1.4	Should	Provide accurate SOC prediction within ± 2%.
	State of Health	E4.2.1	Shall	Estimate and provide the battery's State of Health (SOH)
		E4.2.4	Shall	Support remote SOH calculation
		E4.2.5	Shall	SOH uncertainty is ≤ 4%
		E4.2.6	Should	SOH uncertainty is ≤ 2%
	Available Power	E4.3.1	Shall	Provide available battery power
	Balancing	E4.4.1	Shall	Provide cell and module balancing.
	Location	E4.7.1	Shall	Be able to acquire its location information (GPS coordinates) without the use of vessel infrastructure
	Internet connection	E4.8.1	Shall	Support wireless connection to the internet via GSM
		E4.8.2	Shall	Support wireless connection to the internet via WIFI
Functional Behavior	Measurements	E5.1.1	Shall	Measure the current on each electrical building block operating at the system level voltage.
		E5.1.2	Shall	Measure the voltage of each electrical building block.
		E5.1.3	Shall	Measure voltage for each cell group

Requirement Category	Description	Requirement ID [E]	Type	Target
		E5.1.4	Shall	Measure cell or module temperature
	Alert System	E5.5.2	Shall	Provide an alert for any abnormal condition in the battery system.
		E5.5.3	Shall	Activation of protective safety functions shall give an alert.
		E5.5.4	Shall	Abnormal conditions that can develop into safety hazards shall be alarmed before reaching the hazardous level. Sensors and other components used for such alarms shall be separate from emergency shutdown or other protective safety functions.
		E5.5.8	Shall	Provide an alert for high cell or module temperature.
		E5.5.9	Shall	Provide an alert for over and under voltage.
		E5.5.10	Shall	Provide an alert for battery disconnection.
		E5.5.11	Shall	Provide an alert for tripping of battery breakers/contactor.
		E5.5.12	Shall	Provide an alert for communication alarm.
		E5.5.13	Shall	Provide an alert for liquid cooling leakage.
		E5.5.14	Shall	Provide unbalanced cell voltage.
		E5.5.15	Shall	Provide insulation monitoring
	Diagnostics	E5.7.1	Shall	Provide local diagnostics.
		E5.7.2	Shall	Provide remote diagnostics.
	Over-Current	E5.10.1	Shall	Protect against over-current by disconnection of the battery system
	Over-Voltage	E5.11.1	Shall	Protect against over-voltage by disconnection of the battery system
	Under-Voltage	E5.12.1	Shall	Protect against under-voltage by disconnection of the battery system
	Over-Temperature	E5.13.1	Shall	Protect against over-temperature by disconnection of the battery system
Communication	System Bus	E6.1.3	Shall	Communicate the voltage and discharge/charge current limits.

Requirement Category	Description	Requirement ID [E]	Type	Target
Safety	Over Charge Protection	E8.1.1	Shall	Incorporate redundant analog and digital safety with configurable limits
	Failure Modes	E8.9.1	Shall	Any faults isolate only the electrical building block it originated in, allowing continued operation of the system at the highest-level electrical block.
	E-Stop	E8.12.1	Shall	The battery system shall be equipped with an independent emergency shutdown for disconnection of the battery system.
Security	Data Transfer	E9.1.1	Shall	Incorporate cyber security in all data traffic to / from BMS.
Tools	Remote Monitoring	E10.1.1	Shall	Include remote monitoring
		E10.1.3	Shall	Provide real time location tracking
Reliability	Useful Life	C14.1.1	Shall	Support 10-year life
		C14.1.2	Should	Support 20-year life
	Shelf Life	C14.2.1	Shall	Support 10-year life
		C14.2.2	Should	Support 20-year life

3.2.5. Smart Cell Supervisor (1.1.1.2.1)

Requirement for smart cell supervisor are presented in Table 6.

Table 6. Smart Cell Supervisor

Requirement Category	Description	Requirement ID [F]	Type	Target
General Information	Objective	F1.2.1	Reference	The development of a Single Cell Supervisor component with coupled first line controller as part of a battery management system with the goal for reducing costs, maximizing safety and amount of energy contained within a 20' shipping container
Functional Behavior	Measurements	F5.1.1	Shall	Measure voltage (V) for each cell or group.
		F5.1.2	Shall	Measure temperature (T) of each cell group.
	Balancing	F5.2.1	Shall	Passively balance each cell group

		F5.2.2	Should	Actively balance each cell group
	Data and commands	F5.3.1	Shall	Perform local measurement data conversion
		F5.3.3	Should	Store cell group historical data locally.

3.2.6. Ultrasound Sensor (1.1.1.2.2)

Requirement for ultrasound sensor are presented in Table 7.

Table 7. Ultrasound Sensor

Requirement Category	Description	Requirement ID [AD]	Type	Target
General Information	Objective	AD1.2.1	Reference	The development / integration of an Ultrasound sound sensor with the goal for reducing costs, maximizing safety, and increasing battery utilization throughout its operating life
Functional Behavior	State of Charge	AD5.1.1	Shall	Calculate and provide the battery's State of Charge (SOC)
		AD5.1.2	Shall	Have SOC calculation at the lowest level installation unit.
		AD5.1.3	Shall	Provide accurate SOC prediction within ± 5%.
		AD5.1.4	Should	Provide accurate SOC prediction within ± 1%.
	State of Health	AD5.2.1	Shall	Determine the SOH for the lowest level installation unit.
		AD5.2.2	Should	Determine the SOH for each cell
		AD5.2.3	Shall	SOH uncertainty is ≤ 4%
		AD5.2.4	Should	SOH uncertainty is ≤ 1%
	Thermal Runaway Detection	AD5.6.1	Shall	Detect the onset of thermal runaway due to internal gas generation early enough to prevent it from occurring

3.2.7. Cell (1.1.1.3)

Requirements for battery cell are presented in Table 8.

Table 8. Cell

Requirement Category	Description	Requirement ID [G]	Type	Target
General Information	Objective	G1.2.1	Reference	To develop a cell using a novel 3D printing manufacturing technique tailored for the marine industry to reduce cost and increase energy density.
Regulatory	Certifications	G3.1.1	Shall	Meet UN DOT 38.3 requirements
		G3.1.4	Shall	Meet IEC 62619
		G3.1.5	Shall	Meet IEC 62620
		G3.1.5	Shall	Meet UL 1642
	Capacity	G5.7.1	Shall	≥ 59 Ah
	Energy Density	G5.8.1	Shall	≥ 500 Wh/L
		G5.8.2	Should	≥ 580 Wh/L
	Specific Energy	G5.9.1	Shall	≥ 242 Wh/kg
		G5.9.2	Should	≥ 283 Wh/kg
	Cycle Life	G5.10.1	Shall	≥ 12,000 cycles at 70% DOD before reaching 70% BOL capacity.
		G5.10.2	Should	≥ 12,000 cycles at 90% DOD before reaching 70% BOL capacity.
		G5.10.3	Shall	Be capable of being consistently cycled until reaching 70% BOL capacity without cell fallout.
	Calendar Life	G5.11.1	Shall	≥10 years at 25°C at 50% SOC before reaching 80% of BOL capacity
		G5.11.2	Should	≥15 years at 25°C at 50% SOC before reaching 80% of BOL capacity
Testing Requirements	Cell Test Certifications	G6.1.1	Shall	Meet IEC 61233 Cell Test Certification Requirements
		G6.1.2	Shall	Meet UL 1642 Cell Test Certification Requirements

Requirement Category	Description	Requirement ID [G]	Type	Target
		G6.1.3	Shall	Meet IEC 62620 Cell Test Certification Requirements
	Shock	G6.2.1	Shall	UN DOT 38.4, T.4 - Shock
	Vibration	G6.3.1	Shall	UN DOT 38.3, T.3 - Vibration
	Altitude	G6.4.1	Shall	UN DOT 38.3, T.1 - Altitude Simulation
	Thermal Shock	G6.5.1	Shall	UN DOT 38.3, T.2 - Thermal Test
	Short Circuit	G6.6.1	Shall	UN DOT 38.3, T.5 - External Short Circuit
	Impact / Crush	G6.7.1	Shall	UN DOT 38.3, T.6 - Impact / Crush
	Overcharge	G6.8.1	Shall	UN DOT 38.3, T.7 - Overcharge
	Forced Discharge	G6.9.1	Shall	UN DOT 38.3 T.8, - Forced Discharge

3.2.8. Cathode (1.1.1.3.1)

Requirements for cathode are presented in Table 9.

Table 9. Cathode

Requirement Category	Description	Requirement ID [H]	Type	Target
General Information	Objective	H1.2.1	Shall	Develop a cathode material optimized for Current Direct application requirements.
	Cas Registry Number	H1.3.1	Shall	CAS No- 182442-95-1
Full Cell Performance	Reversible Discharge Capacity	H6.1.1	Shall	>150 mAh/g
		H6.1.2	Should	>185 mAh/g

3.3. T2.5 Analysis and Specification of Recyclability

Lead: Umicore; Contributors: Spear, Blackstone, VUB

This task will generate a set of design guides D2.1 for the Current Direct Waterborne Transport Battery Container. It will include the impacts of all non-cell material selections, disassembly techniques, and the scale of minimum disassembly units permissible for planned recycling processes. A key focus of the task will be designing for safe disassembly, recycling, and disposal of the Current Direct battery containers at their end of life. This will be an input to the Safety assessment in T7.4. This task will include participation in the preliminary and critical design reviews of the Current Direct battery in T4.1 to ensure that at end-of-life future cost of recycling and non-reusable waste is minimized.

3.3.1. Recyclability (1.12)

Requirements for recyclability are presented in Table 10.

Table 10. Recyclability

Requirement Category	Description	Requirement ID [Q]	Type	Target
General Information	Objective	Q1.1.1	Shall	Provide design guideline to achieve an easily recyclable containerized battery system.
Regulatory	Standards	Q3.1.1	Shall	Meet EU Batteries Directive (2006/66/EC)
		Q3.2.1	Should	UN 38.3 Conformity
Performance	Recyclability	Q4.1.1	Shall	Have ≥90% of total waterborne battery container mass be recyclable
		Q4.1.2	Shall	Reduce recycling processing cost 30% when compared to today's containerized waterborne transport battery systems
Safety	Safety Impairing Event Notification	Q5.1.1	Should	Log and notify short circuits or short-term high current loads outside of design recommendations
		Q5.1.2	Should	Log and notify reduced insulation resistance of the complete system

Requirement Category	Description	Requirement ID [Q]	Type	Target
		Q5.1.3	Should	Log and notify system overheating > 70°C
		Q5.1.4	Should	Log and notify deep discharge below the lower control limit of the BMS
		Q5.1.5	Should	Log and notify overcharge exceeding the upper control limit of the BMS
		Q5.1.6	Should	Log and notify strong corrosion of conductive layers
		Q5.1.7	Should	Log and notify undefinable smells.
		Q5.1.8	Should	Log and notify severe deformations of the housing.
		Q5.1.9	Should	Log and notify any signs of burning, molten, or soot residues
		Q5.1.10	Should	Log and notify damaged insulation and seals
		Q5.1.11	Should	Log and notify open / damaged cell housing
		Q5.1.12	Should	Log and notify damaged cooling circuit
		Q5.1.13	Should	Log and notify any apparent abnormal events
Design Requirements Impacting Dismantling	State of Charge	Q6.1.1	Shall	Design to allow easy & safe discharging
		Q6.1.2	Shall	Store EoL battery at State of Charge (SoC)<30 %
	Modularity / Separability	Q6.2.1	Should	Allow maximum modularity of the components
		Q6.2.2	Should	Allow maximum acceptability of the components
		Q6.2.3	Should	Allow standardization among similar and other major applications
		Q6.2.4	Should	Allow separation of cooling components

Requirement Category	Description	Requirement ID [Q]	Type	Target
		Q6.2.5	Should	Use of maximum number of non-permanent electrical cell connections
	Component Uniformity	Q6.3.1	Should	Maximum the use of similar fasteners / connectors
	Material Selection	Q6.4.1	Should	Use of similar plastic / polymer materials
		Q6.4.2	Should	Use of similar alloying elements for metals used.
		Q6.4.3	Should	Avoid/minimize use of Glues / Adhesives / thermal pastes
		Q6.4.4	Should	Minimize organic material
	Weight	Q6.5.1	Should	Have ergonomic design for manually handled units.
		Q6.5.2	Should	Limit manually handled unit weights to ≤ 20kg
		Q6.5.3	Should	Follow ADR regulation
	Voltage	Q6.6.1	Should	Include voltage labeling
Design requirements impacting Recycling	Size	Q7.1.1	Should	Minimize and standardize module
	Chemical composition	Q7.2.1	Should	Minimize impurities
		Q7.2.2	Should	Avoid/minimize use of heavy metals

4. PATH FORWARD

The requirement specification written has been divided into requirements that needs to be in place for the demonstration unit timetable as well as for the requirements for the commercialization. At this stage, the deliverable contains mainly requirements related to the demonstration unit. The specification requirement work continues and will follow the project schedule.

Additional internal / external workshops have been planned to further define / refine requirements for capture and definition to refine the needed items for the demonstration unit, followed by the requirements towards the commercialization.

Furthermore, a requirements relational data base is under development to provide intelligence, analytics and insights that will drive future phases of the project.

Market research and workshops will be conducted to develop further understanding of applicable ship types and required shore infrastructure for the service of Current Direct.