GUIDE TO EXPLORE THE USE OF ORGANIC RFB FOR LARGE INFRASTRUCTURES ENERGY STORAGE IN WARM COUNTRIES AND HEAVY MULTICYCLE USES

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Definition
RES	Renewable Energy Sources
BMS	Battery Management System
PLC	Programmable Logic Controller
SCADA	Supervisory Control And Data Aquisition
FB	Flow Battery
EMS	Energy Management System

1. Introduction

1.1. BALIHT objectives

The European Union sets ambitious targets for energy transition from fossil-fuel energy production to renewable energy sources. However, energy production from renewable sources is intermittent as it relies on weather conditions (sun exposure, wind power, etc.). In order to match energy production from RES and demand, there is therefore a growing need for energy storage. Flow batteries are a promising solution for medium to long-term energy storage.

Flow batteries (FB) have an operation temperature of 40°C typically. However, discharging the battery generates heat, which can cause degradation or malfunction of its components. Cooling requires energy, devices and consumables reducing the battery overall efficiency, and increasing its OPEX and CAPEX. Moreover, higher temperatures have advantages like lower electrolyte viscosity (less pump energy), better electrolyte diffusion in electrode and an increase in battery power due to an increase of the ion mobility.

BALIHT project aims to develop a new organic redox flow battery suitable to work in warm environments, with a life-cycle similar to current organic ones thanks to components that can reach high temperatures (80°C > T > 60°C). This feature would make BALIHT battery 20% more energy-efficient than actual FB since cooling systems are not required, less pump energy is necessary and higher power efficiency can be achieved. BALIHT battery would therefore be fit for use in harsh weather conditions.

BALIHT battery also has high environmental, economic, social and safety standards targets. Indeed, this redox-flow battery technology is based on aqueous solution for its electrolytes. Electrolytes themselves come from organic sources: they are made out of preliminary products which can be obtained out of lignin. Lignin is a natural and renewable raw material and is available in sufficient amounts as by-product from existing pulp production. BALIHT represents an alternative to batteries using precious and critical raw materials and uses cheaper and environmentally-friendly materials coming from clean supply-chains. BALIHT is also a safe energy storage solution: by relying on organic, aqueous and non-hazardous substances, the lack of risk of flammability or explosion is close to zero, making it a fit solution for use in populated or industrial areas.

BALIHT prototype battery is to be installed in Ibiza's harbour new terminal, where it will be used as an energy storage facility for energy produced by photovoltaic plants, with the aim of powering EVs charging points and the terminal's new infrastructures.

1.2. Scope and structure of the guide

This 'Guide to explore the use of organic redox flow batteries for large infrastructures energy storage in warm countries and heavy multicycle uses' contributes to the technology transfer and dissemination of BALIHT results.

The document summarises the main developments and achievements obtained during the project. It presents the main features of the components and technologies which have been developed within the project, and which are being for most of them integrated in BALIHT battery.

Section 2. summarises the main components and technologies developed within the project. All components and technologies stated all had the same overall objectives: to be suitable to be integrated in an organic redox-flow battery, to show high-level of resistance and performance when working under higher temperature levels, as well as to be as environmentally and costly-friendly as possible.

Section 3. gives an overview of the social, environmental and toxicological impact of BALIHT battery, compared to current solutions on the market.

1.3. BALIHT partners

All partners contributed to the elaboration of this guide. For each result, the name of the partners involved will be stated. As this Guide is made to shared publicly, any further information on more sensitive or business-related issues shall be directly requested to the partners involved in the development of the result of interest.

You will find in the table below a short description of each of BALIHT partners involved in the definition and development of the technologies and components of the battery, of the engineering studies, of the installed.

NAME	COUNTRY	SHORT DESCRIPTION	ROLE IN THE PROJECT
Asociación de Investigación de Materiales Plásticos y Conexas AIMPLAS PLASTICS TECHNOLOGY CENTRE	Spain	Technology center focused on the plastics industry	AIMPLAS is the project's coordinator, and develops the battery's plastic formulations optimised for both heavy-duty use in high temperatures, and for chemical and mechanical resistance.
COBRA instalaciones y Servicios S.A. cobra GRUPO	Spain	Grupo COBRA has 70 years' experience in maintenance services and activities across various distribution networks.	COBRA provides the project with its expertise to ensure optimal market uptake, and coordinates the development of the final prototype of the battery.
ETRA Research & Development etra I+D	Spain	Hi-tech unit within ETRA Group, one of the leading industrial groups in Spain.	ETRA I+D is responsible for the development and implementation of an energy management system in the BALIHT redox flow battery, and contributes to the project's various studies.
KU Leuven M²S – cMACS – Membrane Technology Group	Belgium	The largest university in Belgium in terms of research funding and conducts fundamental and applied research in all academic disciplines.	The group provides the project with expertise on membrane development, from laboratory to scale-up, and contributes to various studies throughout the project.

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KU LEUVEN			
Mann+HUMMEL GmBH MANN+HUMMEL	Germany	Leading global expert in the field of filtration solutions, with applications for motor cars, industrial use, air filtration and sustainable water use.	The firm supports the development of the membranes of the BALIIHT battery and contributes to the various environmental, social and economic studies of the project.
Tecnodimension Hincable, SL TECNODIMENSION	Spain	Family business founded in 2001 by a group of professionals in the design and production of inflatable structures and textile architecture	The business is responsible for the design and manufacture of the flexible tanks that store the electrolytes and contributes to BALIHT's environmental, social and economic studies.
CMBlu Energy AG cmblu energy ag	Germany	The company develops organic flow batteries for various applications throughout the energy value chain.	The company is responsible for developing and building BALIHT's battery including its electrolyte, and contributes to the environmental, social and economic studies of the project.

University Leiden. Faculty of Science, Institute of Environmental Sciences CML	Netherlands	The team is specialised in strategic multidisciplinary research on the sustainable management of natural resources, biodiversity and environmental quality.	The group is responsible for life-cycle analysis, social LCA and market acceptance of BALIHT. It also researches regulatory and safety-by-design aspects, and toxicology.
KONČAR Digital	Croatia	Digital solution provider and developer of digital platforms based on open and modular architecture for power engineering, mobility, and critical and urban infrastructure, with advanced analytics and lifecycle management.	The firm develops and implements BALIHT's battery management system software, and contributes to the environmental, social and economic studies.
Autoritat Portuària de Balears	Spain	Port Authority of the Balearic Islands, which manages and operates the ports of Palma, Alcúdia, Maó, Eivissa and la Savina.	As a potential end-user of BALIHT's battery, the Port Authority supports COBRA in defining the requirements of the Port that will need to be met in order to optimise the demonstrator battery.

1.4. Document updates

The document will be updated as the project comes to an end. The document will be disseminated during two workshops aiming at showcasing BALIHT project's results, achievements and lessons learned. The outcomes of the workshops, such as needs of clarification from the audience or comments from the partners will be integrated to provide the most comprehensive document as possible. The document will also integrate the first results of BALIHT battery on-site testing, which is to take place over the 2023 summer.

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2. Main characteristics and components of BALIHT battery

The following sections introduce BALIHT technologies specifically developed during the project by our team. It gives more insight on the ambitions, the technology routes and the final outputs obtained through the research and development actions ran by our consortium of partners.

Most of the components and technologies listed below are integrated in BALIHT prototype battery, which is to be installed in Eivissa. Some of the components could not go to production phase in a timely manner for them to be properly integrated in the battery, but will be used for other further developments.

The project also aimed at developing polymeric membranes with high performance in warm environments. For this reason, this technology will not be detailed in a dedicated section below.

2.1. Organic-based electrolyte suitable for heavy multi-cycling at high temperatures

Partners involved: CMBlu

The organic solid-flow battery consists of two separate electrolyte systems, the posolyte and the negolyte system. Both systems have a depot which stores the bulk capacity and a shuttle which transmits the electric energy between the depot and the electrodes. The depots are solids which are stored in the tanks, the shuttles are aqueous solutions which are pumped between tank and electrodes. The chemical structure of the ingredients, their synthesis and the recipes of the electrolytes are subject to continuous improvement to optimize the performance of the batteries.

Throughout the first months of the project, a number of promising electrolyte candidates made out of lignin and applicable in aqueous redox-flow battery applications at elevated temperatures were identified. Concretely, BALIHT battery relies on the mixing of two liquids: Ferrocyanide electrolyte solution (FAT) and DHPS.

2.2. Plastic frames without significant deformation at temperatures up to 80°C

Partners involved: MHDE, Schunk, AIMPLAS

The thermoplastic matrix was mixed with different additives, fillers, and fibres to produce materials with enhanced thermal properties. Different approaches were followed to do so, including the increment of the crystallinity of the plastic material itself; the combination of the reinforce polymer matrix that will improve mechanical properties; and the post-treatment of the samples produced with new formulated plastics.

After running research and tests on several materials, a reinforce formulation was upscaled and tested in a prototype stack and battery. This formula was selected because it is able to double the heat deflection temperature while reducing the expansion to half of the reference material. Also, due to the need for these frames to be isolating and cost-effective.

2.3. Thin and flexible carbon-based electrodes with a 150% of current reaction kinetics

Partners involved: Schunk, AIMPLAS

The project aimed at developing bipolar, thin and flexible electrodes. Due to these requirements, producing such plates required a higher amount of material compared to conventional electrodes.

Several formulations have been tested to reach improved properties, such as temperature resistance and mechanical stability up to 80°C.

The selected formulation, combining increased polymer content and the use of carbonaceous fillers with different morphologies, showed improved mechanical and electrical properties, which would meet the requirements of a new operation temperature of a battery to 60°C, while showing better processability during the embossing process.

The bipolar plates are gas-tight, allowing them to be integrated in the new stack. They are embossed to generate a structure on the electrode surface. This structure holds the membrane in the middle of the cell and avoids contact of membrane and electrode which results in inactive surface on the electrode. After embossing the electrodes, they need an active surface which is necessary to transfer electrons through the electrode. The plates did not show any leakage after the embossing process.

2.4. Flexible tanks designs with thermal resistance up to 80°C and easy cleaning & electrolyte evacuation

Partners involved: AIMPLAS, Tecnodimension

For the sake of the project, the two electrolyte solutions would be stored in canvas tanks located right next to the central battery and driven by the energy generated in renewable energy receivers. To ensure stability and safe operation, the flexible tanks are positioned in a rigid container. This way any leakage will be collected in the container and the tanks are mechanically protected from external influences. The containers are based on standardized pallet boxes which are mounted with dividing plates, so the tank sets are fixed within their volume.

A flexible thin-walled solution is proposed for these tanks to be adaptable to change in shape and volumes while keeping thermal and mechanical stability. A specific fabric was used, that can keep high temperatures of 60-80°C or higher without any consequences either deformations or modifications.

Moreover, coatings that operate at higher temperatures were developed to tailor the interphase electrolyte/container to ensure good flowability and chemical resistance.

On the other hand, on these flexible containers, printed sensors were successfully integrated and showed good response for detecting leakages of the electrolyte, if any.

2.5. Modular Battery Management System optimised for oRFB working on warm environment

Partner responsible: KONCAR Digital

The Battery Management System (BMS) represents the system of components that are responsible for operating the BALIHT battery. The system is responsible for data acquisition, data processing and data storage, temperature management, pressure management, flow speed management, safety management, acquisition of voltage and current, and the communication with other systems (EMS) and sensors. RFB's Battery Management System main function is to control pumps which runs positive and negative electrolyte simultaneously and respectively runs charging or discharging of the battery. While pumps are not running, the battery remains at the last stage of charge.

For the purpose of BALIHT project, BMS for BALIHT battery was designed to meet all needs of the project specifics, meaning the following:

- BMS is using robust industrial equipment that can bear harsh environmental conditions as BALIHT battery is predicted to be working in warm environments. This includes a central controlling device suitable to work in extended temperature range (from -20°C to +60°C)
- BMS is designed to be scalable so it can easily be adjusted for the batteries with other requirements and specifications (meaning for different energy requirements).
- BMS uses SCADA that supports the operation with equipment from various producers and communication protocols.

The BMS was set up to be able to work under complex uses of BALIHT battery, such as the one where the battery is powered in a mixed way (power grid + photovoltaic cells) and the power stored is used to charge electric vehicles and for the energy power demand shaving peaks and consumption of the terminal. The power generated in photovoltaic cells would be stored in the battery together with the power required by the grid and would power electric vehicles in charge and Botafoc's terminal energy supply. The aim is to get the maximum degree of power self-sufficiency of the terminal.

The main component of BMS is Programmable logic controller (PLC), device responsible for collecting data from sensors, pumps, valves and other measuring instrumentation and controlling the battery charging and discharging process.

Finally, one main feature of the BMS is the KONCAR-developed SCADA System called PROZA.Net, which is to be installed on industrial computer in control room. It consists of several graphical screens (based on windowed displays) with real time data. SCADA collects data from PLC and EMS and presents them in user friendly graphical interfaces in a real-time environment. PROZA NET also allows the use of MS office tools (Excel, Access) for system access, data analysis from real-time databases or archived database and independent report making.

BMS controls pumps and that can only be obtained when all the inputs from different measuring equipment reach its PLC and are working properly. BALIHT's RFB has the different sensors installed to measure:

- Temperature of the electrolyte
- Voltage
- Current

- Pressure in posolyte and negolyte tanks
- Leakage detection inside the battery tank

The BMS works in a way that it communicates at the same time with the EMS and sensors/actuators (valves and pumps) and sends relevant data to the EMS. Based on all received inputs (from the BMS and from the grid, EV chargers, solar panels), the EMS decides how to operate the battery, meaning whether to charge or to discharge the battery and defines the charge/discharge power. The setpoint command is sent to the BMS and the PLC forwards this command to the pumps which run the electrolyte. In this way the EMS and the BMS continuously monitor and control the battery operation. For more information on EMS, see Sub-section 2.7.

2.6. Energy Management System including RFB features

Partner responsible: ETRA

The Energy management system (EMS) can be defined as a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation or transmission system.

For the application of BALIHT project the EMS can be considered as an element responsible for the optimization of the battery's behavior during its operation. For the EMS to operate properly it must consider the constraints and boundary conditions not only of the storage system but also the installation in which the battery is installed. In a nutshell the EMS allows the optimization of the energy balance for the whole system (battery - consumption - grid). Considering the main functionalities of the EMS, it will allow the communication between the battery and the RES plants and additionally.

The main benefits for the customers will be the better use of the resources available and the increasing of revenues due to the economical optimization.

The proposed EMS has been developed considering the RFB restrictions and the possible restrictions for other types of batteries such as li-ion batteries or even hydrogen storage systems achieving a flexible EMS. As defined in the DOA, within the BALIHT projects an EMS will be developed and implemented in the RFB to act as an interface between the system embedding the RFB and the BMS.

Specifically, the EMS optimizes the integration of the RFB both technically and economically, allowing RFB systems to take advantage of its potential to be deployed in Smart Grids.

2.7. Battery design: high degree of flexibility in installation and operation

Partner responsible: CMBlu

The final design of the battery aims at integrating the requirements rising from the characteristics of the components and technologies developed throughout the project's stages.

The philosophy of the battery design is to create a modular system with a high grade of flexibility in controlling the segments. By breaking down the main battery system in smaller subsystems, a high modular design is created where every subsystem has its own parameters excluded from the rest. The design philosophy of breaking down the main battery in smaller stand-alone systems enables a high degree of flexibility in installation and operation.

Every segment has its own pair of tanks and pumps which are integrated in standardized pallet sized containers. The tanks are flexible, which allows the electrolyte and depot to Increase and decrease in volume.

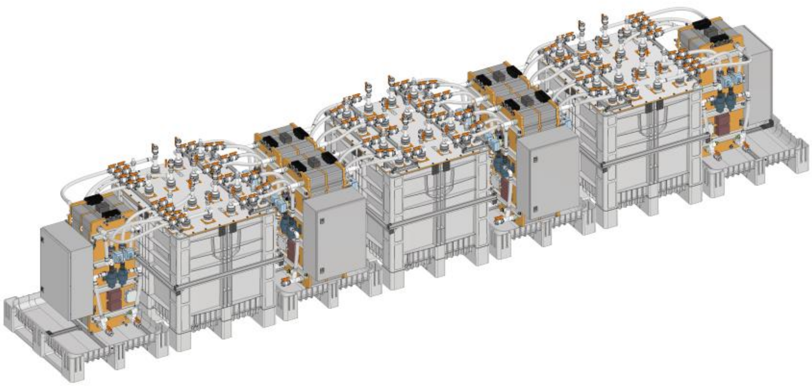
The design is based on standardized pallet systems to create easy transport possibilities and a flexible installation on site. Indeed, the standardised pallets bring modularity which enable the battery to be transported and installed by means of forklift equipment. The segments are also mounted on standardized pallet with an integrated collecting basin in case of leakage of the electrolyte.

Because of the pre-assembled setup with a double valve principle, the interconnections between the tanks and the segments can be executed without spillage or leakage of the electrolytes.

To ensure an extra safety, the flexible tanks containing the electrolyte are installed in a container equipped with separation compartments, covering any high voltage components.

The design allows to present future products with low installation times and easy to scale up.

3D Visual of the battery design:



2.8. Procedures to operate and maintain an oRFB

Partner responsible: COBRA

The new technology developed in the BALIHT project, the organic flow battery, presented a new problem in terms of how to work with such different characteristics compared to conventional batteries.

Procedures of operation and maintenance of the oRFB were set out inside the BALIHT project taking in to account the unique characteristics that the battery presents.

These characteristics include but aren't limited to, all the considerations needed to work and maintain the specially designed electrolyte (including safety and security issues), monitoring and spare parts, the need for inspections and preventative maintenance as well as all the services and requirements set out by both the partners included and the operators.

These procedures help to ensure that the battery will work correctly and at its optimized level for as long as possible.

3. Social, economic and regulatory aspects of the battery

Partner responsible: LEIDEN University

Due to its organic electrolytes, a key achievement of the proposed BALIHT battery design is the fact that not only the climate change impacts appears to be slightly lower than the LIB and VRFB references, but that this is achieved without the use of metals like lithium and cobalt, and even vanadium which may be problematic for environmental, social and supply security reasons.

The battery's operational performance parameters such as roundtrip efficiency and depth-of-discharge are the most influential to the battery's life cycle impact scores, and any further improvements in this respect will not only enhance the technological and economic competitiveness of the battery but its environmental sustainability as well.

By implementing standard occupational health & safety procedures and controls, the manufacturing and operation of the battery can be conducted in a safe way and with risk exposures that are within acceptable thresholds for the industry. The proposed online, realtime monitoring systems will play a key role in the most significant risks. Direct exposure of workers to potentially hazardous chemicals is not expected to occur except for unintentional substandard operation conditions or accidents. In such cases, personal protective equipment along with appropriate emergency response procedures and equipment will substiantially mitigate the undesired health and safety effects.

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