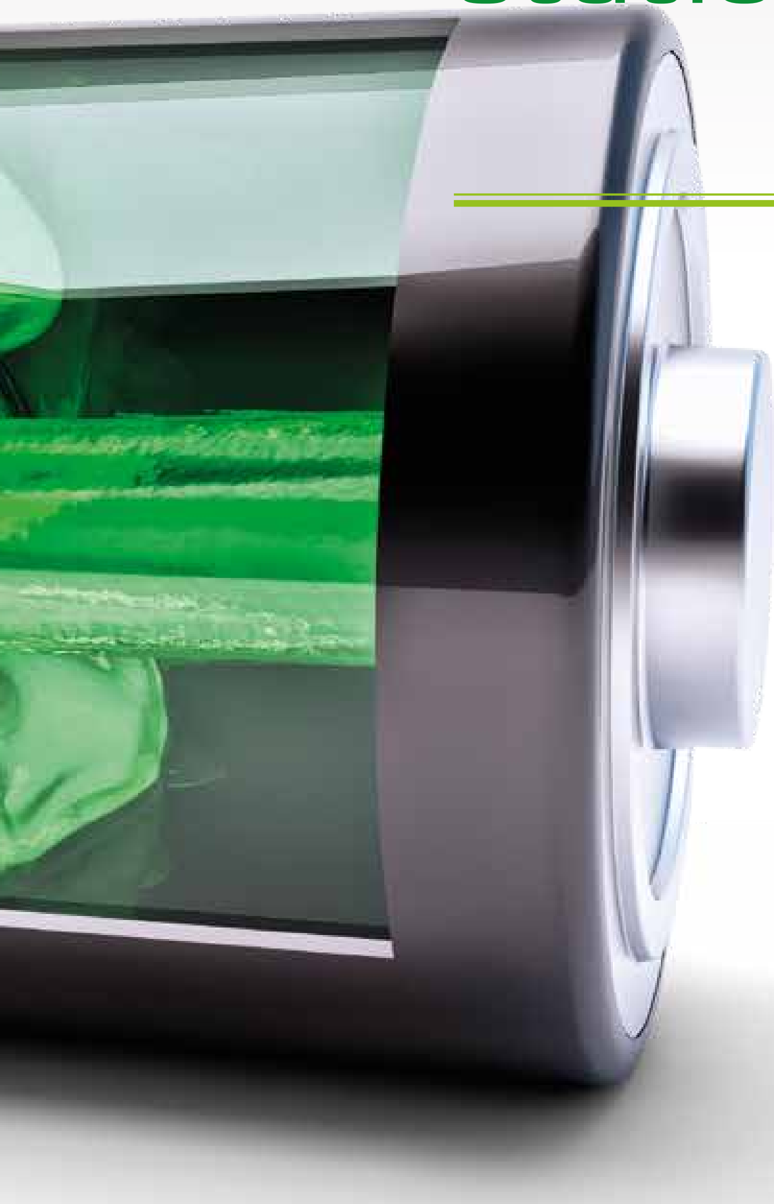
FLORES

Network of Flow Battery Research Initiatives

Flow battery systems and their future in stationary energy storage



SEPTEMBER 2021

Main Author

Dr. Peter Fischer, Fraunhofer ICT, peter.fischer@ict.fraunhofer.de, +49 721 4640 891

Disclaimer

The HRB - Horizon Results Booster is an initiative funded by the European Commission, Directorate General for Research and Innovation, Unit J5, Common Service for Horizon 2020 Information and Data.

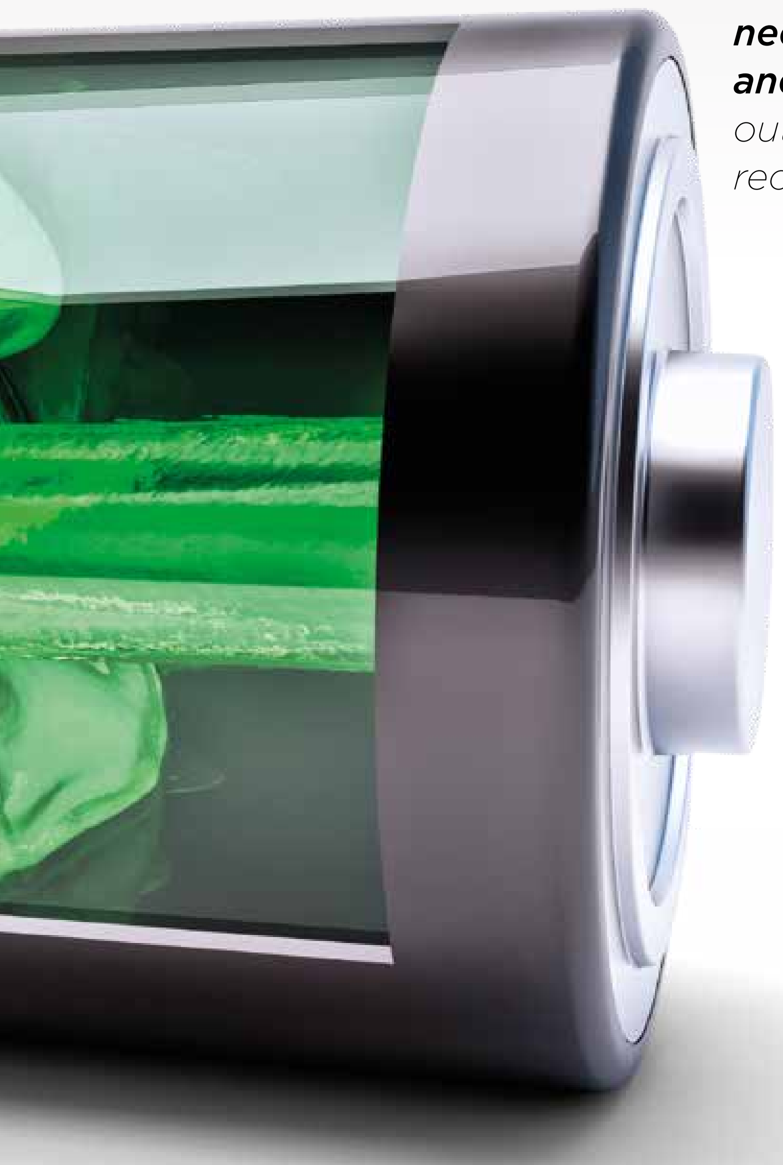
The FLORES projects have received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement no. 875637 (BALIHT), 950038 (Bi3BoostFlowBat), 875605 (CUBER), 875565 (CompBat), 765289 (FlowCamp), 875613 (HIGREEW), 963652 (HYBRIS), 963550 (HyFlow), 875524 (MELODY), 726217 (MFreeB), 851272 (NanoMMES), 860403 (Polystorage) and 875489 (SONAR – network coordinator)

Flow battery systems and their future in stationary energy storage

- 13 EU-funded projects, including
- 89 organisations from academia and industry
- 1 international symposium with approx. 250 delegates

Learn the outcome of our discussions!

*On 9th July 2021, at the Summer Symposium of the International Flow Battery Forum, the FLORES Network of Flow-Battery Research Initiatives held a workshop to **identify research needs, barriers, potential markets and impacts of flow batteries**. The outcomes, including resulting policy recommendations, are provided here.*



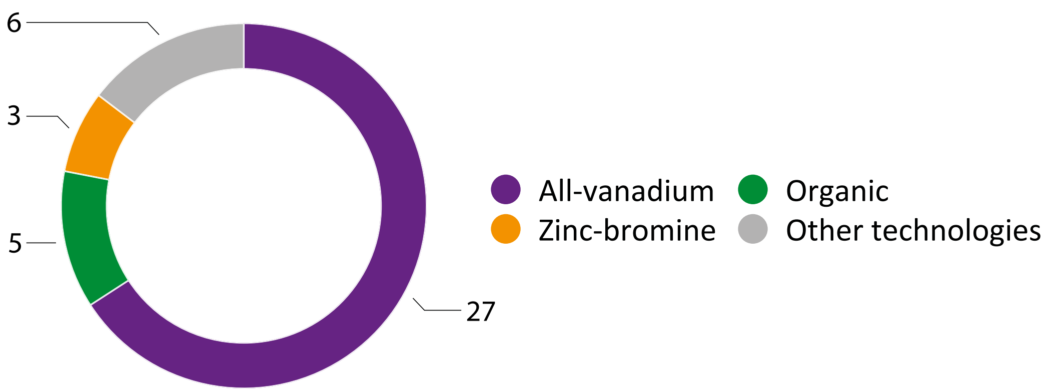
Starting point

Redox flow batteries (RFBs) are a versatile energy storage solution offering significant potential in the transitioning energy market. However, they often fall beneath the radar of policy makers and end users, in part because they are considered as an immature or emerging technology. This is despite one RFB system – all-vanadium storage – gaining a significant market over the last decade. The largest known RFB storage system today - with 800MWh – has been constructed recently in the Chinese province of Dalian in 2021.

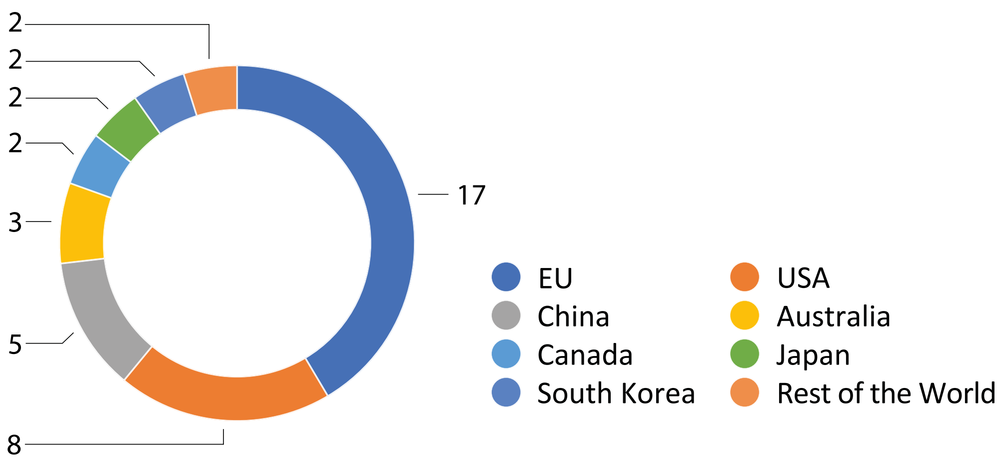
Flow battery industry: There are 41 known, actively operating flow battery manufacturers, more than 65% of which are working on all-vanadium flow batteries. There is a strong flow battery industry in Europe and a large value chain already exists in Europe. Around 41% (17) of all flow battery companies are located within Europe, including five start-ups working with emerging and new RFB systems. A strong economic backbone of material suppliers has evolved over time; for example, three of the largest carbon electrode producers[1] and two larger membrane producers[2] are located in Europe.

Europe is a major development hub for RFB technology

No. of companies worldwide working on different RFB systems



Location of flow battery companies



1 SGL Carbon, Mersen, Zoltek
2 Fumatech, Solvay,

Applications and markets: Flow batteries are a very versatile storage technology with a long lifetime and high cycle numbers. For short-duration cycles below 15 minutes they cannot match the efficiency and cost structure of lithium-ion batteries. However, unlike lithium-ion batteries, flow batteries are capable of deep-cycles. As a result, they can be used for long-duration stationary storage in the range of several hours of rated power. In addition, the individual scalability of energy and power in RFB systems helps to reduce the costs of long duration storage. The relatively cheap energy component (electrolyte) makes them ideal for cost-efficient longer duration storage solutions, including peak-shaving and peak shifting operation. In combination with renewable energies, flow batteries can deliver considerably lower levelized costs than other stationary storage technologies.

The major problem for flow battery manufacturers in Europe is the current energy market mechanisms in the time of transition: renewable energy sources have been subsidized in the past, and coal and nuclear power plants are still active, keeping prices for flexibility services down. This makes grid-operated mid- to long duration energy storage uneconomical, leaving the main market for more profitable short-duration services like frequency regulation. For this application, lithium-ion batteries are unbeatably competitive. However, for full-duty cycles of several hours rated power, such short-term storage solutions experience reduced life-times.

As fossil energy generators are phased out, the demand for longer-duration storage will increase. In the U.S. preparations are already underway: there, the energy market is regulated by the individual states, and storage durations of 6-8 h are often required if new renewable power plants are connected to the grid. The new strategy has led to a start-up boom in longer duration systems and particularly flow battery companies in the U.S. To facilitate the transition towards renewables in Europe, a similar restructuring of the energy market is required.

Current policy

The European Commission has adopted a number of measures to enable storage, notably through the Clean Energy Package. "fit for 55" package proposed by the Commission in July 2021 will further drive demand for storage (inter-alia through more ambitious renewable energy target for 2030)

Some of the SET-Pan targets for battery performance have nearly been reached, but there are still open issues. For example, in order to achieve the goal of 0.05€/kWh·cycle stated in the SET-plan, the operating life time of an all-vanadium flow battery would have to increase to more than 25 years, due to the high costs of vanadium (vanadium costs = 60 – 80€/kWh). These time frames are far from technical periods of amortisation, which are usually 5 to 10 years for storage batteries.

In order to meet these economic goals in the SET-plan while also enabling mid- and long-duration energy storage, R&I funding is required for new and more durable storage materials and new recycling technologies or more durable storage materials.

Development of a policy brief: who was involved?

The FLORES Network of Flow Battery Research Initiatives is made up of 14 EU-funded projects, with 89 participating organisations and a total funding of >€41 million. The network aims to increase the visibility and impact of flow battery technology.

Its expertise covers the entire value chain from modelling and material research through to prototypes and recycling and includes several different RFB variants.

FLORES research expertise

- Modelling electrolite chemistry SONAR compbat
- Modelling cell/stacks SONAR compbat FLOW CAMP
- New active materials BALIHT CuBER HIGREEW MFreeB Bi3Boost FlowBat POLYSTORAGE FLOW CAMP NanoMMES
- New electrolyte chemistry MELODY BALIHT CuBER HIGREEW MFreeB Bi3Boost FlowBat POLYSTORAGE FLOW CAMP NanoMMES
- New cell/system concepts MELODY compbat MFreeB Bi3Boost FlowBat POLYSTORAGE
- New control agorithm & power BALIHT CuBER HIGREEW HyFlow HYBRIS
- Techno-economic modelling SONAR
- LCA/LCC HyFlow MELODY
- Recycling HyFlow

A panel of nine representatives from the FLORES projects moderated parallel discussion groups covering all aspects of flow battery research, development and application:

Four leading industrial experts were interviewed to identify commercial needs. FLORES experts and industry experts engaged with the delegated of the IFBF conference.

The platform could not have been larger: each year the IFBF brings together 250 delegates from around the world to meet, learn, discuss and raise the profile of flow batteries.

The outcomes

The policy workshop aimed to create a comprehensive overview of flow battery research and application, in the areas of

- Modelling and materials
- Application, demonstration and validation
- Roadmapping

An original document prepared by the FLORES network was examined, corrected and completed through interactive discussions with each expert panel.

Materials & modelling

Technology and status	Besides the established vanadium RFBs, several other cell chemistries are available, and more are on the way to be discovered via state-of-the-art computer-aided methodologies like those researched in the EU-funded projects COMPBAT and SONAR. However, only a **few of them have moved beyond pilot studies to reach (pre)commercial status**. The active materials such as membranes, carbon electrodes and bipolar plates currently used in RFBs are **by-products of either fuel cell research or other technologies** (example: electrode felts were mainly developed as high temperature oven insulation material). Only very few materials are designed especially for RFB applications.
Potential markets	Beneficiaries of new research outcomes could be 1) Flow battery producers; 2) producers of chemicals, e.g. basic chemicals related to organic redox-active molecules; 3) producers of cell materials like membranes, bipolar plates and felt electrodes; 4) modelling and control tools developers.
Research needs	1) Exploration of **new redox-active compounds** as potential RFB electrolytes. Computational techniques such as DFT, molecular dynamics or computer-aided search engines, like the methods developed in the EU-funded projects SONAR, COMPBAT and MFreeB, will accelerate the discovery of promising new redox compounds. These first results must be thoroughly investigated and validated. 2) Especially new redox active organic compounds for AORFB can disrupt the existing approaches. For this, the **low-cost, industrially feasible and environmentally sustainable production of organic active materials** (as in the EU-funded projects HIGREEW or BALIHT) needs to be investigated further. 3) Attention should also be paid to **new inorganic chemistries** for next-generation RFBs (as in the projects FlowCamp and MELODY). Especially metal complexes are an interesting new field of electrolyte research, with various new approaches on the horizon. 4) Adapted or **radically new cell designs** are likely needed for unconventional chemistries and concepts such as i) slurry-type batteries with redox-active polymers addressed in the project POLYSTORAGE or with ii) inorganic slurries like zinc slurry air batteries in the project FlowCamp, iii) membrane-free RFB cells (projects MFreeB and MELODY) or iv) customized materials for the new concepts, such as solid booster materials which are being initially investigated in the projects COMPBAT and B3BOOST FLOWBAT

Materials & modelling

	5) **Customized materials** for new systems like membranes, felts, bipolar plates for aqueous organic RFBs (HIGREEW membranes modified to mitigate crossover). Especially new RFB chemistries like HBFB, all-copper, AORFB, and solid boosters will require different cell materials and cell configuration. Modelling/design is also needed here to evaluate thermic, fluidic and electrochemical aspects. 6) Recycling or reuse strategies for battery materials and electrolytes, like the recycled VRFB electrolyte in the project HyFlow
Policy challenges	Although in the previous Horizon 2020 research framework programme several (LC-BAT) calls funded material research for RFBs, new systems are still in the early development stages, and even more advanced systems have not yet achieved commercial application, mostly due to a perception that RFBs have higher cost and higher environmental impact. A challenge is that benefits of these technologies are expected more in the mid-term: a **focus on quick solutions and early results will limit the chance to find breakthrough ideas** (competing technologies including VRFB have progressed over a long period). However, unless **continued research and technology validation** is funded (e.g. in the next Cluster 5 Work Programme for 2023-2024), there is a risk that the technologies will remain in the “valley of death”.
Policy recommendations	Further investments are required in **material research** for existing flow batteries as well as new technologies, along the whole TRL scale from 4-7. Efforts for innovative **upscaling and production technologies** as well as **standardization** could be the focus for more advanced materials. An important opportunity would be the inclusion of redox flow technology in the next Cluster 5 WP for 2023-2024 calls, which would pave the way for promising results generated within current EU-funded projects to be moved further along the TRL scale. It would also help to reinforce the presence of redox flow technology in ERA (European Research Agenda), political and industrial plans. In funding material research for flow batteries, it is important to consider that technology development needs a **long-term research framework** - it cannot be tackled with short term approaches.

Application, demonstration & validation

Technology and status	There are **very few RFB demonstration projects**, and still fewer for the purpose of research and validation
Potential markets	The beneficiaries of demonstration and validation projects would be utilities, electric energy suppliers, transmission grid providers, companies and private citizens, both as individuals and as energy communities, and end users and legislative bodies creating technical regulations for the energy market.
Research needs	1) New, **medium-to-large scale living labs for the testing of different RFB components** (RFBs are modular, so new materials and systems could be tested) or for comparative testing of storage or charging infrastructure for electric vehicles

	2) New, **large-scale living labs for grid-operated storage** with flow batteries, which can operate beyond the regulatory framework to explore the application of RFBs in new markets (e.g. grid booster approaches, hybrid storage and virtual inertia). 3) Projects with **emphasis on the topic of grid technology and control with energy storage** (building on work begun in projects HYFLOW and HYBRIS). 4) **New sensors** (especially SOC) and control strategies to maintain SOH to achieve an "indefinite" life time of a flow battery. 5) **Smart battery management** to elongate battery life (such as the Battery Management System (BMS) development in HIGREEW and BALIHT).
Policy challenges	**Validation of RFBs on a large scale has not yet been achieved**. Current Horizon Europe calls, which could have funded such demonstrators, are mainly focused on hydrogen applications, excluding RFBs despite their high potential to also solve the challenges presented (often the calls indicate a technological preference, e.g. referring to either hydrogen or battery cells). **Regulators should incentivise network operators to procure storage** services to invest in more stable grid operation, like recommended in the clean energy package norms. This would release stress from the grid operators and reduce also costly redispatch. **Market incentives and business models are needed to define other services** energy storage could provide like virtual inertia/ grid forming (high power RFB or hybrid energy storage), energy security (seasonal storage) or better utilization of land lines (grid booster). These market strategies should be of highest importance, as energy security is an economic requirement in Europe.
Policy recommendations	Funding calls for **demonstration projects** (for example within Cluster 5 of the EU framework programme Horizon Europe) should be **technology neutral / open** to RFB technologies. Policy research concerning reform regulatory architectures should be encouraged to ensure storage is considered as a key element. They should enable data generation and the validation of RFB technologies and offer the **chance to adjust current regulations** to increase utilization of renewable energies. They should also facilitate mid-size scale up and demonstration projects for material qualification that are more feasible for SMEs and RTOs

Integration of RFBs into technology toolbox / roadmapping

Technology and status	**RFBs are usually not included in energy storage studies**, or at most only VRFBs are considered. This is because the market for long duration storage is not currently profitable (as old and new generation technologies compete on the energy market), or is covered by mainly hydrogen roadmaps, which see energy storage as a by-product of mobility studies. This is one reason RFBs are perceived as an immature, non-commercial technology. LCA, LCC and technoeconomic modelling (e.g. LCOE, LCOS) is carried out for several individual RFB projects, but comparative studies are lacking. Studies on circular economy and recycling strategies for this type of batteries are still in their infancy.
Potential markets	The beneficiaries of more comprehensive roadmaps and comparative studies are decision makers (public- and private sector) and investors.
Research needs	1) **Comprehensive, comparative studies on environmental impact (LCA), techno-economics, sustainability and key performance indicators** for different sectors encompassing all energy storage technologies. 2) **Development of a database for LCA studies** for all energy storage solutions (materials toxicity, end of life). 3) Identification of conditions which are best suited for the adoption of RFBs, and accordingly the **development of new business opportunities/ incentives, e.g. for mid- and ultra-long duration storage** (especially grid-connected storage which is currently highly underestimated). 4) Establishment of **development goals for new materials** for RFBs or RFB systems (comparable to the DOE criteria for fuel cells).
Policy challenges	Comparative studies and roadmaps are focussed on LIB storage and **underestimate the importance of mid-duration storage** and the benefit of potential revenue stacking (short + long duration storage). With the phase-out of old generation technologies, **new business models for long and ultra-long energy storage must be developed**, as huge amounts of storage capacity will be required for flexible energy distribution of renewable energy. These technologies will not be developed by an unregulated market. Also, the **short duration energy storage market must be newly organized**. The need to use battery storage to contribute to momentary reserve in the grid will increase as more rotating masses are phased out. High power RFBs e.g. could provide useful short and long duration storage in one device, cutting costs. In combination with renewables they can be regarded as a real alternative, replacing conventional power plants.
Policy recommendations	As more data is generated on the potential of RFBs, these technologies should be **integrated into technology toolboxes and roadmaps**. This could be implemented via the strategic research and innovation agenda (e.g. funding for networking with existing battery networks). The funding could help initiatives, like implementing similar standards like the PEF standard developed for traction batteries for flow batteries.

Outcomes and impacts (all RFB technology areas)

The mid-term outcome of targeted R&D funding and regulatory change will be that existing and new RFB systems will become more **commercially viable** due to reduced cost and improved durability. RFB systems have a further advantage in terms of **easier maintenance, recyclability and reusability**.

The implementation of large-scale demonstrators will help to generate valuable **data and operation knowledge** in applications beyond the regulatory framework. This will help to shape legislation and improve market mechanisms for a **more resilient energy supply** with highly intermittent power sources. The increased utilization of renewable power sources will help to prevent curtailments and reach climate goals more easily while maintaining the necessary energy security.

Mid-duration storage solutions are one of the most easily implementable flexibility options to meet energy demand and supply, which could have significant benefits for the **peak-shaving and peak shifting of renewables**, especially photovoltaic power generation. This will lead to new business models and opportunities. Mid-duration storage options like flow batteries must therefore become an integral part in **roadmaps**, providing a broader view on the energy storage landscape including the added value of RFBs, and new tools for evaluating the technicality of storage for different application fields.

In the longer-term the specific advantages of RFBs will contribute to EU strategies, e.g.

- Circular economy, as the use of fluids as a storage medium gives RFBs a recycling advantage over other battery types.
- Industrial sovereignty and leadership in energy storage, as the whole RFB value chain is based in the EU, including numerous start-ups fulfilling the European Industrial Strategy.
- EU independence of critical raw materials implementing resources which are not on the list of strategic materials of the European Raw Materials Alliance (ERMA).

What next?

The FLORES Network of Flow Battery Research Initiatives remains active and open to new members. Its future activities include:

- Shaping future funding programmes: Starting from the developed policy brief, the FLORES network offers technical expertise to the European Union and national and regional funding agencies to ensure a close link between funding and market needs
- Establishing connections with the "European Battery Alliance" (EBA), "Batteries Europe initiative" and "Advanced Materials for Batteries Partnership" (AMBP), "Batteries European Partnership Association" (BEPA), "Association for Storage of Energy" (EASE), "Flow Batteries Europe"(FBE) as well as national lobby groups such as the German Energy Storage Association (BVES), the Spanish Energy Storage Association AEPIBAL or the Polish Energy Storage Association (PSME) and the roadmap Batteries 2030+,
- Contributing to technology roadmaps: several FLORES members are involved in the Battery 2030+ initiative, and are coordinating a joint contribution to its roadmap
- Increasing the visibility and impact of flow battery technology: the network will continue its active involvement in promoting flow battery research and development, and exploring potential applications. Join us for example at the EU Sustainable Energy Week in October 2021.
- Disseminating the latest flow battery research: follow our activities for example on www.linkedin.com/company/flores---network-of-flow-battery-research-initiatives

Join our community

flowcamp-project.eu

Grant Agreement No. 765289

sonar-redox.eu

Grant Agreement No. 875489

higreew-project.eu

Grant Agreement No. 875613

cuberproject.com

Grant Agreement No. 875605

polystorage-etn.eu

Grant Agreement No. 860403

melodyproject.eu

Grant Agreement No. 875524

baliht.eu

Grant Agreement No. 875637

compbat.eu

Grant Agreement No. 875565

cordis.europa.eu/project/id/726217/es

Grant Agreement No. 726217

cordis.europa.eu/project/id/950038

Grant Agreement No. 950038

hyflow-h2020.eu

Grant Agreement No. 963550

imperial.ac.uk/song-group/research/nanommes-erc-starting-grant

Grant Agreement No. 851272

hybris-project.eu

Grant Agreement No. 963652

FLORES

Network of Flow Battery Research Initiatives

The HRB - Horizon Results Booster is an initiative funded by the European Commission, Directorate General for Research and Innovation, Unit J5, Common Service for Horizon 2020 Information and Data.