# FLOW BATTERIES SUSTAINABILITY STORY

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# FLOW BATTERIES
## Sustainability Story

A flow battery is a short- and long-duration energy storage solution with sustainability advantages over other technologies. These include long durability and lifespan, low operating costs, non-flammable design, minor safety risks, and low environmental impact from manufacturing and operation. Flow batteries, therefore, present a largely untapped potential to support and accelerate the transition from fossil fuels.

### 1. Flow battery basics

**Redox flow batteries (RFBs), also called batteries with external storage, are an energy storage technology developed with sustainability in mind, that can be used for both long- and short-duration energy storage applications.** They are designed for large-scale and potentially cost-effective energy storage with a discharge power over a longer period of time (4h or more). To do this, flow batteries require large amounts of electrolytes.

A flow battery is a type of rechargeable battery that stores energy in liquid electrolyte solutions. Fig. 1 presents a schematic illustration of a typical flow battery system.

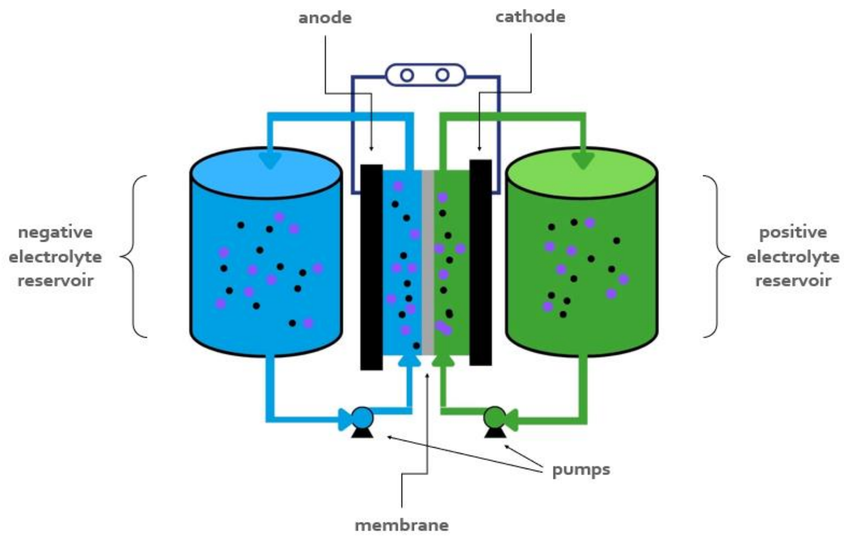


Fig. 1. Typical structural configuration of a redox flow battery.

Two important components of flow batteries are their positive and negative electrodes, which are separated by a membrane. The electrolytes on each side are flown through the corresponding cell stack when the flow battery is charged and discharged. The energy storage capacity of flow batteries can easily be scaled up or down by changing the size of these external electrolyte reservoirs, allowing for a high level of scalability and flexibility. The external electrolyte tanks allow flow batteries to be recharged often and for a long period of time. This is done through reversed chemical half-reactions, simplifying their recharging process compared to various other batteries. **These features make flow batteries ideal for long-duration and large-scale energy storage applications, especially for fluctuating renewables linking wind or photovoltaic.**

## 2. Procurement of raw materials and production

Next to the technologies already industrialised, several flow battery models explore innovative electrolyte chemistries, including those based on metals and organic redox species. The goal is to build a flow battery that has a long lifetime and that surpasses the average capabilities of battery technologies. Indeed, the overall sustainability of flow batteries largely depends on the components used as redox species. Over 50 variants of electrolytes are described in the literature.[1,2] For metal-based flow batteries, widely investigated chemistries include iron/chromium RFBs, zinc/iron RFBs, zinc/bromide RFBs, however, it is the vanadium RFBs (VRFBs) that have been the most commercialised and developed in the energy market.[3] Meanwhile, market entry of organic (metal-free) flow batteries is also advancing quickly.[4] The most common organic redox species that have been used so far are carbonyl groups (quinones/anthraquinones), metallocenes (such as ferrocene derivatives), nitroxide radicals, viologen derivatives and others.[5]

### a) Metal-based flow batteries

Flow batteries with electrolytes based on metals such as iron and vanadium are created with abundantly available materials. Different methods are used to produce vanadium: through mining or by recovery from waste materials such as petroleum residues.[6] Vanadium is classified as a critical raw material (CRM) due to its importance for the clean energy transition and supply risks. However, untapped reserves of vanadium mineral deposits in Norway and Finland will increase European supplies in the coming years.[7] **The EU CRMs Act will likewise diversify and strengthen regional supply chains of all CRMs, including vanadium, thus supporting regional self-sufficiency**.[8]

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1 Redox flow batteries: a sustainable technology | CIC energiGUNE
2 Redox flow batteries: Status and perspective towards sustainable stationary energy storage
3 Recent Progress in Organic Species for Redox Flow Batteries
4 Organic Flow Batteries: Recent Progress and Perspectives | Energy & Fuels
5 Recent Progress in Organic Species for Redox Flow Batteries
6 Vanadium: A catalyst for EU's Green deal? | Norge Mining
7 Win-Win for Europe: Mineral processing facility in Finland set to increase vanadium production for Europe | EIT RawMaterials
8 European Critical Raw Materials Act | European Commission

The abiotic resource depletion potential, describing the estimated dilution of resources (in kg Sb-eq/kWh capacity), is extremely low for iron redox flow batteries (IRFBs) and VRFBs at 0.001 and 0.003 respectively.[9]

### b) Organic flow batteries

**Organic chemistries are synthesised from abundantly available materials, thus are highly sustainable**. New chemistries are being discovered and early results are very promising. **Research shows that flow batteries can be produced with non-corrosive and readily available materials (such as iron sulphates, lignin or bio-polymers).**[10] These minimise environmental impacts and safely enable large-scale deployment.

Additionally, aqueous organic redox flow batteries (AORBF) seem to present promising properties and advantages economically. Organic redox species are abundant and their properties like solubility, conductivity and electrochemical reversibility are tuneable by adding some specific functional groups.

## 3. Advantages

### a) Scalability

As it was mentioned above, flow battery technology is modular and scalable. For some technologies, the power and capacity of the flow battery can be scaled independently from each other by separate sizing of the reservoir volume and the cell stacks. **This enables the creation of easily customisable battery that can cater for a vast array of applications.**[11] In addition, by adjusting the size of the external storage components, the energy capacity requirement of a flow battery can be accommodated. As a result, when a redox flow battery system is scaled up to a level where the weight or volume of the battery is relatively insignificant compared to that of the stored fuel and oxidant, **the system can achieve its theoretical energy density**.[12]

Contrary to flow batteries, batteries with internal storage accumulate the electro-active materials internally and electrodes are themselves part of the electrochemical fuel. Both the power density and the energy density of the battery with internal storage are determined by the features of the negative and positive electrodes. These dual functions not only affect the performance over time but also make a conventional battery unable to scale up – it can only be scaled out, meaning applying more modules with identical parts.[13]

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[9] Flow battery production: Materials selection and environmental impact
[10] New flow battery could help unlock renewable energy | usc.edu
[11] Redox-Flow Batteries: From Metals to Organic Redox Active Materials
[12] Flow Batteries| The Electrochemical Society Interface
[13] Flow Batteries| The Electrochemical Society Interface

### b) Performance, safety and durability

Flow batteries have a **long operational life, with certain models exceeding** 20 000 cycles and 20 years, notably zinc/bromide flow batteries (ZBFBs) and VRFBs.[14] They **can cycle and recharge throughout this period with almost no loss in power**.[15] This feature results in a very low specific cost (€/kWh/cycles/efficiency), approaching the 5 c€/kWh target proposed by energy administrations of various countries. A longer lifetime allows to amortise the capital costs of a longer period and to reduce the amount of active material needed to supply power throughout the necessary discharge duration. In general, flow batteries experience minor detrimental effects of deep discharge, experience minor self-discharge and have low maintenance requirements.[16] It is important to note that **flow batteries promise to be more competitive than other solutions in cases where renewable energy sources dominate the energy mix.**

A comparable significant advantage of flow batteries is their **low flammability, as the key component of the non-flammable electrolyte is water**.[17] Flow batteries pose no explosion risks because they operate with liquids at near-atmospheric pressure. Another essential safety feature is storing the active materials apart from the reactive point source in a flow battery. In case of shorting during when the pumps are active, most of the heat is transferred to the electrolyte in reservoirs, where volume is much higher than in the stacks, so temperatures in reservoirs rise slowly enough to allow the system to avert unsafe situations.[18]

Safety studies conducted on VRFB showed that the technology is stable to external shorting and causes no smoke, leakage or fire under numerous realistic scenarios, while also remaining with no changes in cycling efficiency.[19] Furthermore, because some flow battery technologies can be discharged completely during maintenance activities, they can perform in safer conditions.[20] Indeed, flow batteries offer the highest level of safety compared to any other battery technology on the market today.

**In conjunction with ease of recyclability and safe operation, flow batteries have a promising circularity of production.**

### c) Recyclability and circularity

**Flow batteries offer significant advantages over competing technologies in terms of material reuse and recycling.** For example, vanadium sulphate electrolytes

[14] Solving the Technical and Economic Challenges to Reprocessing VRFB Electrolyte | U.S. VANADIUM
[15] Why Vanadium Flow Batteries May Be the Future of Utility-Scale Energy Storage | Forbes
[16] Flow Batteries| The Electrochemical Society Interface
[17] Can Flow Batteries compete with Li-ion? | DNV
[18] Critical safety features of the vanadium redox flow battery
[19] Critical safety features of the vanadium redox flow battery
[20] Can Flow Batteries compete with Li-ion? | DNV

used in VRFBs can be easily recovered and reused, with up to 95% of all components being recyclable.[21,22,23,24]

Additionally, the electrolytes can be freed in existing recycling streams without additional purification, while individual metals can be recycled in large quantities while preserving the quality.[25] These capabilities make flow batteries an attractive option for sustainable resource management and waste reduction.[26] As research continues, we can expect further advances in the recycling capabilities of flow battery technologies.

### d) Green jobs

The twin energy and digital transitions will transform European labour markets. According to the European Centre for the Development of Vocational Training, the energy transition will cause **medium-skilled roles to be concentrated in sectors such as extraction industries, construction, and waste management, while employment increases in service sectors will occur for engineering and administrative roles**.[27] The increasing demand for energy storage will provide new employment opportunities in the sector: **investment in the energy storage industry will create 170 000 new jobs in Europe by 2030**.[28] Reskilling policies will likewise help redirect employment towards cleaner production in most other energy-related sectors.[29]

## 4. Conclusion

To conclude, flow batteries stand out from other technologies due to their numerous sustainability and reliability advantages. Their material availability and scalability mean that they can be easily expanded to meet changing energy storage needs. In terms of performance, flow batteries have a longer lifespan compared to other battery technologies, making them a more durable and reliable option for long-term energy storage.

Recently, batteries with external storage were included in the Batteries Regulation, which aims to modernise the EU's legislative framework for batteries by setting harmonised laws for dealing with the entire life cycle, from production and deployment to waste management of batteries.

The inclusion of flow batteries in the crucial sustainability provisions of the Batteries Regulation, such as the Battery Passport and the declaration of carbon footprint

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21 Flow battery systems and their future in stationary energy storage | FLORES
22 Solving the Technical and Economic Challenges to Reprocessing VRFB Electrolyte | U.S. VANADIUM
23 What is a flow battery? | The International Flow Battery Forum
24 Life Cycle Assessment of a Vanadium Redox Flow Battery
25 Flow battery systems and their future in stationary energy storage | FLORES
26 Flow battery systems and their future in stationary energy storage | FLORES
27 The green employment and skills transformation | CEDEFOP
28 Outlook for jobs creation in European battery industry | Menon Economics
29 The green employment and skills transformation | CEDEFOP

calculation will allow industrial actors to provide valuable information on the environmental impact of production and use, including carbon footprints. It ensures that the Batteries Regulation is neutral towards different technologies while providing a more comprehensive comparison of energy storage technologies that does not discourage the use of flow batteries. This would allow for a more accurate comparison of the sustainability of flow batteries and other battery technologies on the market, ensuring greater control for producers and more transparency for customers.

## FOR FURTHER INFORMATION

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## ABOUT FLOW BATTERIES EUROPE

Flow Batteries Europe (FBE) represents flow battery stakeholders with a united voice to shape a long-term strategy for the flow battery sector. We aim to provide help to shape the legal framework for flow batteries at the EU level, contribute to the EU decision-making process as well as help to define R&D priorities. Flow Batteries Europe is working to create and reinforce networks between key stakeholders in the flow battery industry.

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