FLOW
BATTERIES
EUROPE

What you need to know about flow batteries

Background information: How battery storage works

A battery storage is a device to **store electrical energy**. Therefore, inside of the battery the received **electrical energy** is **converted** into **chemical energy** and stored in its chemistry (electrolyte).

A chemical reaction, called **redox reaction**, takes place inside of the battery which converts the related substances or reaction partners to others with a different chemical potential. These chemical substances store the energy till it is needed. When the energy is requested, the reversed redox reaction is started, and energy comes out of the battery in form of electricity.

The process is quite easy. If a voltage from outside is applied to the poles of the battery (i.e. an electrical circuit is connected), which has a higher voltage than the voltage of the battery, then energy goes in; the battery is charged. If the external electric circuit applies a voltage lower than the battery voltage, then energy comes out and the battery is discharged.

History of flow batteries

Not all solutions for flow batteries have the same **T**echnology **R**eadiness **L**evel. The concept of flow batteries chemistry was patented already in 1879 in the US, worked out with metal ions in the 1950s in Germany, Nasa worked on the technique in 1970s and a working All-Vanadium RFB has been presented and patented in the 1980s by Maria Skyllas-Kazacos, University of New South Wales. Exactly this old Vanadium RFB, at least its electrolyte is still in operation and according to our knowledge, has neglectable degradation after more than 30 years of operation. In general, the Vanadium redox flow battery is the most developed and thus the most mature redox flow chemistry

What is unique about a flow battery?

Flow batteries have a chemical battery foundation. In most flow batteries we find two **liquified electrolytes (solutions)** which flow and cycle through the area where the energy conversion takes place. This electrolyte is not housed inside this “battery body” and can be stored in separate tanks.

In contrary to typical batteries, a flow battery consists not only of one body (think of batteries used for your watches or mobile phones), instead of that we have **stacks** (arrangement of cells where energy conversion occurs), **electrolyte tanks** to store electrolytes with the energy they contain and a **piping system** with **pumps** to circulate the stored electrolytes with their energy.

This system has the beauty to avoid many given disadvantageous of standard batteries, as to be bound in a “not flexible design”.

Why are flow batteries needed?

Decarbonisation requires **renewable energy sources**, which are intermittent, and this requires large amounts of energy storage to cope with this intermittency. Flow batteries offer a new freedom in the design of energy handling. The flow battery concept permits to **adjust electrical power and stored energy capacity independently**. This is advantageous because by adjusting power and capacity to the desired needs the costs of the storage system can be decreased.

Furthermore, the independent scalability of power and capacity leads in most redox flow batteries to scale effects concerning the costs per kWh. In other words: in contrast to other batteries**, doubling of the kWh does NOT double the costs**! This is a very important advantage of flow batteries for the combination with renewables.

The stacks where the energy conversion takes place defines the power of the battery. If more power is needed, more stacks are used, connected in series or parallel. The overall concept defines the appropriate arrangement. The tanks define energy capacity with their volume and amount of electrolyte included. In theory this volume is unlimited and finally defined by the requirements of the application.

The piping systems allow the electrolyte, which is pushed by pumps through the system, to be energised inside of the stacks and then to be taken back into the tanks to be stored. It means that they have a closed loop cycle with continuous flow of electrolyte. In case of energy to be taken out of the battery, the electrolyte potential is reduced during the flow, but always keeping up the same flow direction of the electrolyte liquid. Clearly speaking, there is no need for inverting the pump rotation.

What advantages does a redox system have over standard batteries?

Neglectable Degradation of Capacity (at 100% of discharge):
For all flow batteries there is the same target: To be free of noteworthy capacity degradation over the full lifetime. Several solutions are in the state of promising for 20 years and longer of continuous operation. There are some specific chemistries which are not yet at this level, and research is still ongoing.

Free of Memory effects:
Depth of discharge is no issue for flow batteries. 100% of discharge is possible for all solutions, same as cycling with lower percentages. Some specific solutions require in regular intervals a full discharge in order to recover and deplete electrodes to get original status. But this is in many applications feasible and not hindering.

No or very limited self-discharge:
Batteries in general suffer from internal chemical reactions which take place also if the batteries are not in use. Chemical reaction partners may pass separators between electrodes and lead to discharge. Some technologies are more affected and others less.

Flow batteries have the advantage, that only the electrolyte which is located inside the stacks may be affected by such processes when pumps are stopped. The remaining electrolyte volume inside of the external tanks, is not affected at all. Considering the distribution of volumes of typical flow batteries between volume in stacks and volume in tanks, then most often the potential volume for discharge is far less than 1%.

Wide temperature range in operation without sophisticated cooling requirements:
Flow batteries may vary inside their own technology community but usually they work in ambient temperature ranges. Normally the big volume of electrolyte keeps the system very stable and is unaffected by ambient temperature changes of daily rhythms. Day and night changes compensate often without having stronger influences. In addition, the produced and stored heat inside of the electrolyte, effected by internal losses, is very easy to be used for heat combined processes.

Flow battery storage systems provide dynamic step function response:
Due to the size of a complete storage solutions and having pumps that need to be switched on and off, people believe that it must be a slow and snugly alternative. That is not the case. The step response is in activated status immediately and if pumps are in operation, **you will not notice any difference to other chemical batteries**. The energy comes in first instance out of the mentioned stacks and their internal electrolyte volume reservoir. A good application dimensioning allows that this energy amount serves for the first time even if the pumps are stopped and bridge the time that is needed to start up the pumps.

Types of redox flow technology on the market

There are many variations of this technology. The combination of chemical elements (galvanic nobility) produces the “driver” for the chemical reaction, and therefore we relate it to the difference in potentials, meaning voltage. There are more than 60 known redox pair combinations and science is working on finding more appropriate combinations to produce as much voltage per cell as possible.

Nearly all types of chemical batteries relate to the redox principle. There are differences if the redox reaction takes place at the surface of the electrode in the electrolyte, or if the electrode is participating in it. Please note that the galvanic element applied, define the no-load voltage of the cell: Lead acid batteries for example have 2.1 volts, Lithium around 3.7 volts. For further information refer to electrochemical series.

WIP

At flow batteries we have the most prominent combination as follows (work in progress) *:

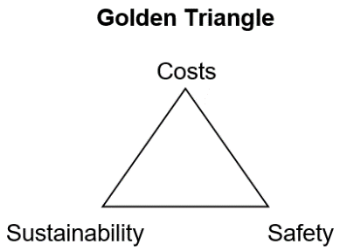
All-Vanadium RFB (VRFB)	1.37 V	15-25 Wh/l	10-40°C
Aqueous Organic Flow Batteries (AORFB)	0,9-1,4 V	≤ 10 Wh/l	
Zinc Bromine RFB (Zn-Br_2 RFB)	1.85 V	30-80 Wh/l	
All-Iron RFB (Fe-RFB)	1.34 V	≈33 Wh/l	5 - 60°C
Iron-Chromium (Fe-Cr-RFB)	1.18 V	8-10 W/l	50-70°C
Hydrogen Bromine RFB (H_2-Br_2-RFB)	1,09 V	50-190 W/l	
Zinc Ferricyanide RFB (Zn-FCY)	1.74V	50 Wh/l	
Zinc Slurry-Air RFB	1,65 V	≈100 Wh/l	

**If there are issues with the above figures, please contact the secretariat.*

Which battery technology is most suited to solve the problems of our society?

It depends very much on the application. While Li-Ion batteries are best suited for mobile applications due to their high energy density, Redox flow batteries (RFB) are most promising to buffer renewables due to their low cycle costs (LCOS) and non-flammability. Additionally, RFB are beneficial for our society due to long lifetime, easy recycling, potential for active materials not based on metals.

According to the opinion of FBE the **flow battery technology offers**, a **potentially wide area for an economic, social and responsible commitment in the field of stationary energy storages**.



Are redox flow batteries sustainable?

Yes, because of the long lifetime and because the active material can be easily recycled. In the view of experts, flow batteries are feasible for large energy storages. This can be interpreted in two ways. One is the storage of large amounts of energy and the other is to be able to discharge the nominal energy for a longer time period. Practically we are speaking of discharging at rated power over 4 hours and more. This requires a large amount of electrolyte.

This initiated the search of adequate electrolytes and the prerequisites are that the basic material allow for various redox states in an efficient way. Therefore, the type and chemical efficiency of electrolytes, the availability on earth, their regional sources and deposits, the way and nature (social) of exploration, so aspects around sustainability, are in the focus of manufacturers and users.

A wide range of chemistries are used and studied. Some are based on metals, some on non-metals, and several are of organic nature. But all solutions are targeting lifetime and that is far beyond of what is currently offered by standard battery technology. Some organic solutions may yet be not able to provide that, but their advantage is the renewable touch and the expected lower cost.

Flow batteries are inherently safe:

A very important issue has come up in the past years with battery explosions and fires, due to loss of control. Safety should be an integral part of the choice for proper storage. Lithium-ion batteries can catch fire. This is a highly unwanted risk in any Li-Ion battery installation and causes several additional costs in Li-Ion battery installations (fire protection measures, insurances, safety distances, …).

However, the majority of RFB on the other hand are inherently safe. They can't catch fire. The main reason is the high amount of water in the electrolytes. RFB often have a very high percentage of water, which makes them inherent safe from fires, anchored in the chemistry. This is obviously a big advantage, because it takes risk out of the equation for operating storages: loss of property, loss of income, and potential production stops.

Safety of course has also to deal with handling, maintaining operations or even transportation. In this respect Lithium batteries have various disadvantages. Here all batteries (flow batteries included) have of course their issues, and the individual impact is related to the chosen chemistry. Due to the gained experience in the past with Lithium-Ion batteries, most solutions for flow batteries avoid super critical materials.

Other considerations in energy storage:

Costs:

The cost approach should include nowadays a 360° perspective to cover all phases of an energy storage device lifetime. Operators of storages should know what they have to expect in the future in order to adopt smart investment and business strategies. Costs have to be compared on a total costs of ownership basis, including not only production and of the energy storage devices, but also the operation time and finally dismantling and the recycling process. Inside of this big picture, it should be possible to discover further important criteria and cost drivers, to finally identify the most suited solution for the requested application.

Sustainability

The definition of sustainability is not always the same. We use this wording in the sense to guide our decision towards a long and safe co-existence of every form of life on earth. In this context, all sustainable decisions should spring from the intersection of economy, society and environment. It is always a trade-off, but flow battery approaches target the costs, evaluate the used materials in terms of social conformity and availability toward a long-lasting use.