MASTER THESIS FINAL VERSION

Moving towards sustainable energy
Market potential, hindrances and related potential policies in EU and China for the Blue acid/base battery

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Abstract

The Blue Acid/Base Battery project aims for a next generation energy storage technology with an Acid/Base flow battery. With a journey from proof of concept to a validated and tested energy storage system, this project attempts to pave the road for cost competitive, environmentally friendly energy storage. Besides technical challenges there are also challenges on introduction to the market and upscaling of this technology.

This study aims at identifying potential hindrances and the market potential for the future application of the Blue acid/base battery. This was done by analyzing governmental policies and regulations, studies on energy storage technologies and niche marketing strategies. Analysis shows several potential hinderances that might influence future application of the Blue acid/base technology, including competing technologies, budget cuts, and social difficulties. The reviewed regulations include pollution emission standards, waste treatment standards, grid connection rules, safety and hygiene standards, governmental funds, tax discounts and subsidies. These regulations can be used as reference for future development and application of the Blue acid/base battery. Potential market opportunities and conditions that need to be met in order to be competitive are showcased through three cases, including energy storage for wind farms in China, energy storage on islands and energy storage for solar panels on the roofs of private homes. The conditions that need to be met include high efficiency, low costs, safety, scalability and the ability to store energy for several months.

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Acronym List

ABFB	Acid/Base Flow Battery
BAoBaB	Acronym for the Blue Acid/Base Battery project
CAES	Compressed Air Energy Storage
EBES	Electrochemical Battery Energy Storage
FBES	Flow Battery Energy Storage
FES	Flywheel Energy Storage
HBES	Hydrogen-based Energy Storage
PHES	Pumped Hydro Energy Storage
TES	Thermal Energy Storage
SNM	Strategic Niche Management
VRFB	Vanadium Redox Flow Battery

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1 Introduction

1.1 Background

With the climate changing and energy consumption increasing, the European Union works towards reduction of greenhouse gas emissions and use of renewable energy resources. The EU has set an target in 2014 for renewable energy to be 20% of the total generated energy resources by 2020. (Commission, 2014) and in in RED II (Renewable Energy Directive 2) the European Union has increased this target for renewable energy to be 32% of the total generated energy by 2030 (Council of the European Union, 2018). By shifting towards renewable energy resources to meet energy needs, the EU lowers the dependence on fossil resources, increasing the sustainability of energy production.

Not only in Europe the installed capacity of renewable energy increases. On a global scale, each year more capacity of renewable energy is added, as seen in Figure 1Figure 1 - Additions by technology. Especially Solar and Wind power show steady growth.

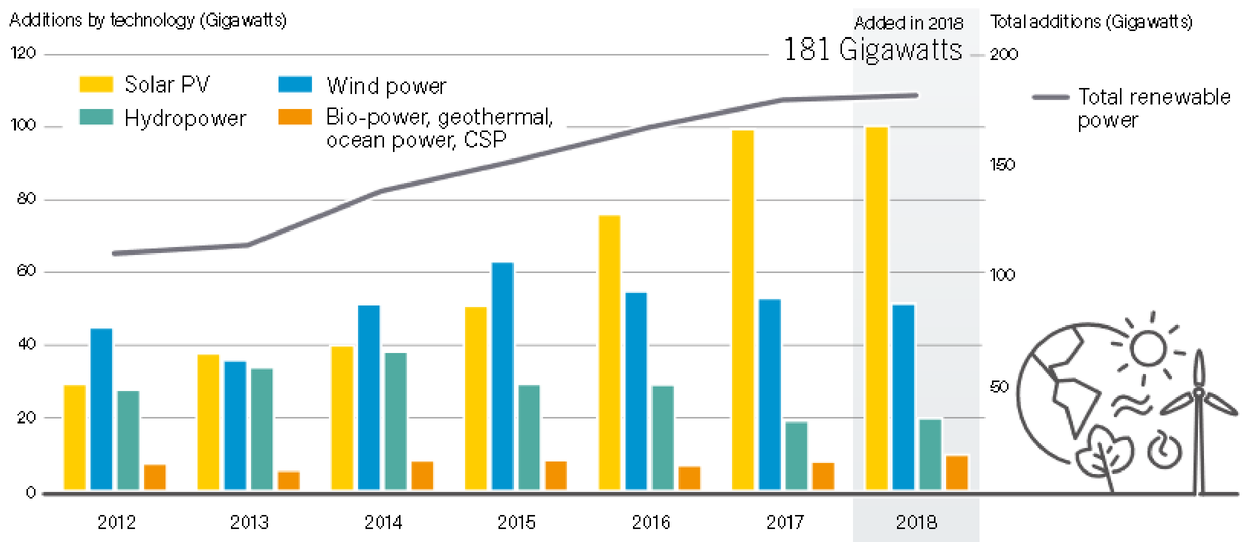

Figure 1 - Additions by technology. Source:(REN21, 2019)

Energy storage is an important element of renewable energy. Renewable energy resources like wind and solar power are highly variable due to the variability in wind strength and presence of sunlight. The power produced does not always match the demand, so systems are required to store excess energy and should be able to deliver in times of high demand or low energy production (Manfrida & Secchi, 2014).

The Blue Acid/Base Battery project, which goes under the acronym BAoBaB, aims for a new solution for energy storage. The basics of this technology is energy storage through the combination of Electrodialysis (ED) and Reverse Electrodialysis (RED) with bipolar membranes. In order to improve the performance of this technology, BAoBaB adds solutions of acid and base, creating a competitive electrical energy storage technology based on pH and salinity gradients (Baobabproject, 2019).

The goal of the BAoBaB project is to understand, improve, test and pave a road for highly efficient, cost-efficient energy storage technology.

1.2 Problem description

1.2.1 Sustainable energy

The majority of the world's power demand is produced by fossil fuel resources. These resources are finite and contribute to the emission of greenhouse gasses, therefore also contributing to global warming. Traditional ways of power generation are not sustainable because they use finite resources and contribute to degradation of ecosystems (Seyed Ehsan Hosseini, 2016).

Sustainable energy uses renewable resources to generate energy. Many countries are making progress towards a shift to sustainable energy. For example: as mentioned before, the European Union has set targets for renewable energy (Commission, 2014), China constructed a roadmap for a shift towards sustainable energy (Management Office of RED programme, 2014) and the Paris Agreement shows that participating countries are willing to reduce emission gasses and finance the development of climate-safe technology (United Nations, 2015).

Examples of sustainable energy resources are wind, solar radiation and biogases. China has areas in the south suitable for solar energy and areas in the north suitable for wind energy (Management Office of RED programme, 2014) and is increasing the amount of wind farms significantly, with a total capacity of 0.5 GW in 2005, 6.1 GW in 2006, 13.6 GW in 2011 and 148 GW in 2015 (LI, et al., 2012; Zhang, Tang, Niu, & Du, 2016). The Netherlands is also moving towards an increase in wind farms (Rijksoverheid, n.d.).

1.2.2 Problems with sustainable energy

Production and use of sustainable energy also introduce some challenges. Power flows are instantaneous, meaning that when power is produced, it should be consumed as well (Mukrimin & Tepe, 2017). Gas turbines, coal fired or nuclear powered energy generators have the flexibility to quickly adapt to fluctuating energy demand (Stram, 2016). Sustainable energy depends on fluctuating resources and do not have the ability to adapt their power supply to the demand. Wind energy depends on the direction and speed of wind and solar energy depends on the presence of sunlight. This proves a challenge, as the power demand can be high when not enough sun or wind is present to produce the power that matches that demand. The opposite also occurs, when these resources are present but the demand is low. A study on wind energy rejection from China describes several problems with wind energy, including the mismatch between power generation and the load of power demand, as shown in Figure 2 (Zhang, Tang, Niu, & Du, 2016). A second problem described in this study is that the power grid has a maximum amount of electricity it can transport and it cannot handle the peak loads of the wind farms, therefore it eventually will reject (and consequently waste) that energy. A third problem is that the construction of updated power grids falls behind, so wind farms only supply to local energy demand. The local energy demand is often low, and with the inability to deliver to the grid, excess energy produced is rejected (Zhang, Tang, Niu, & Du, 2016). Another reason for energy rejection and switching to traditional sources as described by Zhang et al. is to ensure stable operation of coal-fired heat supply units in long-lasting winters in north China.

These problems could be potential opportunities for renewable energy storage technologies such as an acid/base flow battery. A large scale acid/base flow battery can store rejected energy or excess energy that is generated during periods of low demand but high availability of renewable resources. In periods of high demand, the energy storage system could supply energy and can adapt to fluctuating demand.

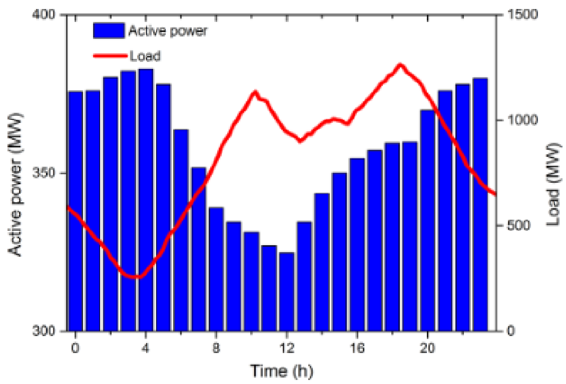

Figure 2 - Mismatch between power generation and power demand. Source: (Zhang, Tang, Niu, & Du, 2016)

When upscaled and introduced to the market, the Blue acid/base battery could contribute to the EU targets of renewable energy and reducing dependence on fossil fuels. For its future application, it is important to look into the potential adoption of this technology by the market and the potential barriers that might influence its upscaling.

1.2.3 Research objectives

The objective of this research is to analyze the blue acid/base battery technology, competing technologies, the markets, and relevant regulations and policies of EU countries and China in order to find out what could be the future potentials and hindrances of the blue acid/base battery. China has been chosen because it could be a big potential market with its developing wind energy solutions (Zhang, Tang, Niu, & Du, 2016). Besides this, China has a large share in the global distribution of vanadium reserves (36% in 2014) (Wu, Wang, Che, & Gu, 2016) and China's vanadium redox flow battery technology was considered to be at leading level in the world in 2015 (Li, Li, Ji, & Yang, 2015). Because the technology of the vanadium redox flow battery is very similar to the blue acid/base battery in terms of operational principles of flow batteries (for details see chapters 3.1.7 and 3.1.8), it can be useful to analyze the Chinese market of the vanadium redox flow battery, as these could also be similar and could provide insights on the Chinese market potentials.

2 Research Design

2.1 Research questions

The main objective of this research has been described as discovering the potentials and hindrances of the blue acid/base battery.

The main research question:

What are the market potentials and hindrances of the blue acid/base battery in EU and China?

This broad research question has been broken down into the following sub-research questions :

Sub-Research Questions:

1. What are the characteristics of the blue acid/base battery and competing technologies?
2. What could be the potential hindrances and niche strategies for developing the battery to a full-scale applied technology in the EU and China?
3. To what extent do policies influence the market potential and occurrence of hindrances in the EU and China (for blue acid/base battery among competing technologies)?
4. Under which conditions can the blue acid/base flow battery be competitive?

2.2 Research framework

In order to make this research more comprehensible, a research framework has been established to show the outlines of this research.

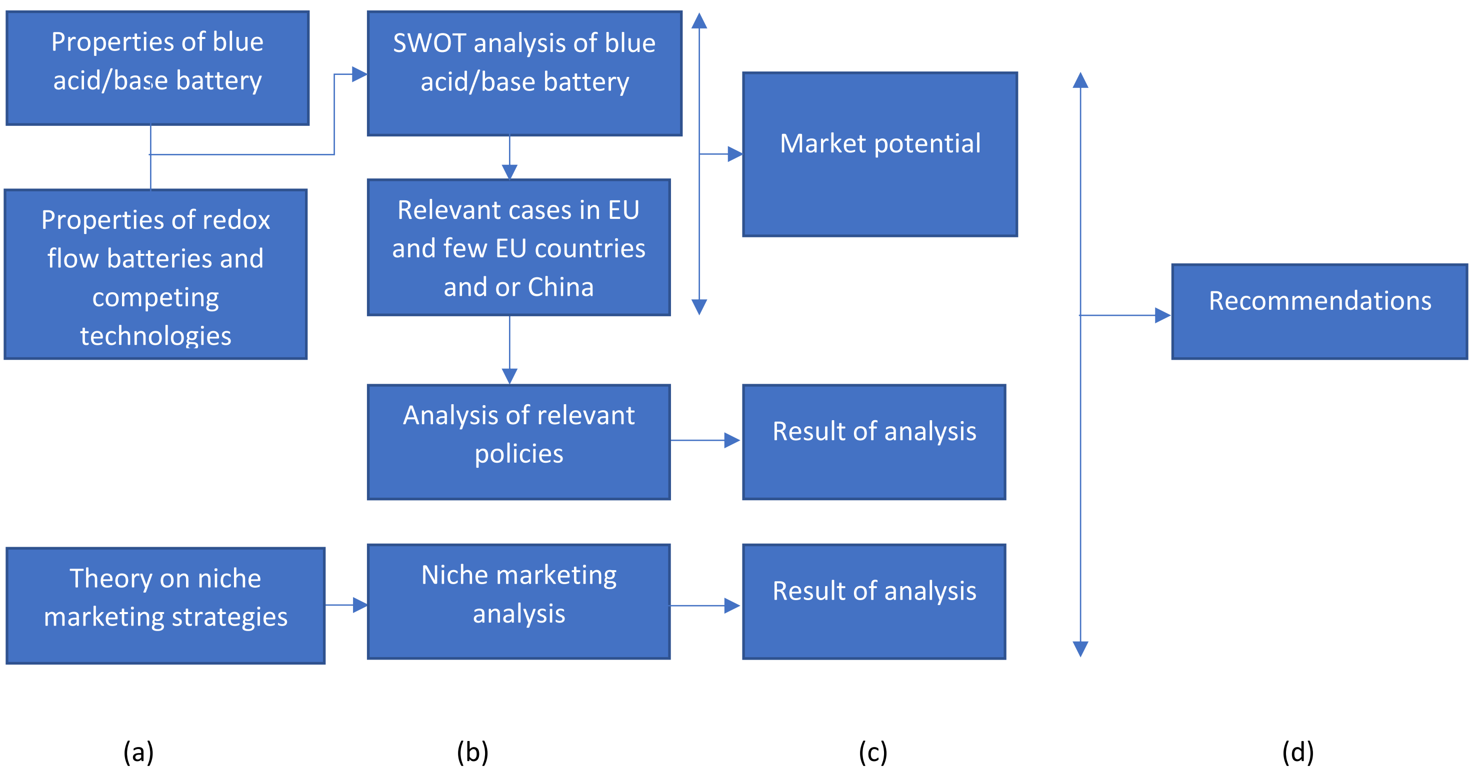

Figure 3 - Research framework

The research framework (Figure 3) can be divided into four columns: a, b, c and d. These columns can be described as follows:
(a) A study on the properties of the blue acid/base battery, competitors and niche marketing strategies (b) by means of which the characteristics of the blue acid/base battery, relevant policies and relevant niche marketing strategies will be analyzed. (c) A comparison of the results of these market potentials of the blue acid/base battery and results of relevant policies and niche marketing strategies will result in (d) recommendations regarding market potentials and hindrances for upscaling the blue acid/base battery.

2.3 Research strategy

This research is basically performed on desk study. The materials collected, e.g. scientific articles, directrices, official EU documents etc., were studied and the information was put in perspective of the research object and analyzed of which the results lead to answers on the research questions. The implementation of this strategy will be described for each research question in the next section. A full list of all the literature works and other sources of information used in this research can be found in chapter 9.

The first research question is "What are the characteristics of the blue acid/base battery and competing technologies?". In order to answer this question, multiple scientific journals have been studied. These publications were found[1] using search words 'Sustainable energy storage', 'energy storage systems', 'wind energy storage China', 'vanadium redox flow battery', etc. The information has been combined to provide for each technology a description, advantages, disadvantages and an entry with properties in Table 1.

To answer the second research question "To what extent do policies influence the market potential and occurrence of hindrances in the EU and China", some different policies were studied by using governmental websites and websites from official organizations. EU policies and directives were found on the official European Union website that provides access to law, regulations and directives[2]. Another website from the European Union[3] was used to find news publications from the European Union on energy storage related topics, which also often referred to directives and regulations. Search words included 'Energy directive', 'Energy grid', 'Waste batteries', 'Environmental regulations for energy storage', etc. Dutch regulations were found on the public Dutch government website for laws[4]. The Dutch implementation of the European directives can be found by searching for the reference number of a European directive on the Dutch governmental website. Chinese policies were found by searching on the Chinese governmental websites[5] using similar search words (e.g. 'Vanadium redox flow battery standards' and 'Vanadium redox flow battery test mode') in Chinese. The found documents have been studied and relevant policies and regulations have been put into a table, parts of this table can be found in chapter 5 and appendix 10.1.

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[1] Using the search functions from the websites www.sciencedirect.com, www.researchgate.net and www.scholar.google.com, of which the latter referred to the first two.
[2] www.eur-lex.europa.eu
[3] www.ec.europa.eu
[4] www.wetten.overheid.nl
[5] www.gov.cn & openstd.samr.gov.cn

For the third research question, “What could be the potential hindrances and niche strategies for developing the battery to a full-scale applied technology in the EU and China?”, literature search was performed[6] using search words such as ‘Strategic niche management’ and ‘Niche marketing’. Additionally, studied literature during the courses at Twente University has also been used. The studied material has been put in perspective of the BAoBaB project in order to identify hinderances and relevant niche marketing strategies.

For the last research question, “Under which conditions can the blue acid/base flow battery be competitive?”, the comparison between the different energy storage technologies created for the first research question has been used as an input combined with three cases encountered throughout the masters programme at Twente University.

[6] On www.sciencedirect.com

3 Comparison of Blue acid/base battery with other technologies

In order to collect objective information about different energy storage technologies, several scientific articles have been studied, including six major publications[7]. The information on energy storage technologies provided by these literature works has been compared and combined into an overview of different technologies, their advantages and disadvantages.

3.1 Energy storage systems

As mentioned in chapter 1.2.2 and as seen in Figure 2, energy from sustainable resources are highly fluctuating and do not match the energy demand. Energy storage solutions are increasingly more important in sustainable energy development to compensate these fluctuations in renewable energy systems. Because it is difficult to store electrical energy directly, energy storage often means transforming electric energy in different styles of energy (Mukrimin & Tepe, 2017). Energy can be stored with different techniques including electrochemical, mechanical, and thermal (Wagner, 2007). Each method can be applied in various situations. Some are suitable for long-term energy storage (i.e. seasonal, energy stored for several months), others for short term energy storage (i.e. several hours to days), some on large scale (i.e. grid connected systems with capacities in MW to GW) and some on smaller scale (capacities of kW to several MW). These energy storage solutions can open up new possibilities for difficulties in application of sustainable energy and can especially be helpful in areas where energy production is intermittent (Wagner, 2007). Some examples for each storage category are given below, which will be used as a benchmark for the blue acid/base battery to aid in the research on its market adaption and up-scaling.

Mechanical Energy Storage

3.1.1 Pumped Hydro Energy Storage (PHES).

PHES is a mature energy storage system which is used in many countries, including China, to compensate the fluctuations in power supply (Zhang, Tang, Niu, & Du, 2016). It involves a technique where water is pumped to a reservoir located in a high location during peak hours of energy generation. The water will be released to a reservoir in a lower location during high demand hours, flowing through a turbine that generates energy (see **Error! Reference source not found.**).

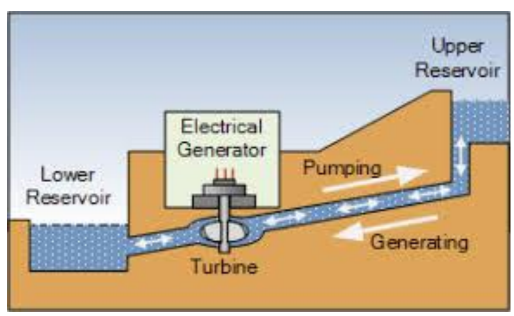


Figure 4 – PHES system. Source: (ICF, 2019)

An example of a PHES system is the pumped-hydroelectricity station in Fengning, HeBei province, China. This is an PHES station from the China Electricity Council and has a planned capacity of 3600 MW (China Electricity Council , 2013).

An advantage of this technology is the high capacity. Natural occurring lakes can act as the reservoirs, storing a large amount of water. With over 300 PHES systems worldwide, it is a mature technology. It has reached low costs and has a fast response time of less than a minute (Kousksou, Bruel, Jamil, Rhafiki, & Zeraouli,

[7] (Mahlia, Saktisahdan , Jannifar , Hasan , & Matseelar, 2014; Mukrimin & Tepe, 2017, Kyriakopoulos & Arabatzis, 2016; Kousksou, Bruel, Jamil, Rhafiki, & Zeraouli, 2014; Stram, 2016; Trainer, 2017).

2014). The stored energy is proportional to the amount of water stored and the height difference between the generator and the reservoir. As long as the amount of water remains equal, there is no self-discharge in PHES systems, which makes it suitable for long term (seasonal) storage. The large capacity of these systems also makes them suitable for energy storage on large scale (grid connected, high capacity).

The most significant limitation of PHES systems are the geographical limitations. The natural occurrence of two large water reservoirs with a difference in altitude is scarce. This system is ideally built on a mountain or hill side with a natural water reservoir uphill, not too far from the location where sustainable energy is generated, but also not too far from a grid connection or storage unit. These ideal situations do not always occur naturally and sometimes require a lot of construction work which can take a long time and requires a high initial financial investment. In addition, PHES systems suffer from great instability problems and vibrations (Zhang, Tang, Niu, & Du, 2016)

3.1.2 Compressed Air Energy Storage (CAES).

This technique stores energy by compressing air during peak hours of energy generation or when energy is cheap. This compressed air is stored and used together with burning gas to operate a combustion engine that generates energy in times of need.

Currently, only 2 large scale CAES plants have been constructed. The first one is Kraftwerk Huntorf, a plant located in Huntorf, Germany with a capacity of 290 MW that can be delivered for 2 hours. It was built in 1978 and belongs to E.ON. The second CAES plant has been built in 1991 in McIntosh, Alabama, USA and has a capacity of 110 MW, which can be delivered for 26 hours. In both cases, the compressed air is stored in naturally occurring underground caves. (Fritz , Klaus-Uwe , & Roland , 2001; Johnson, 2014)

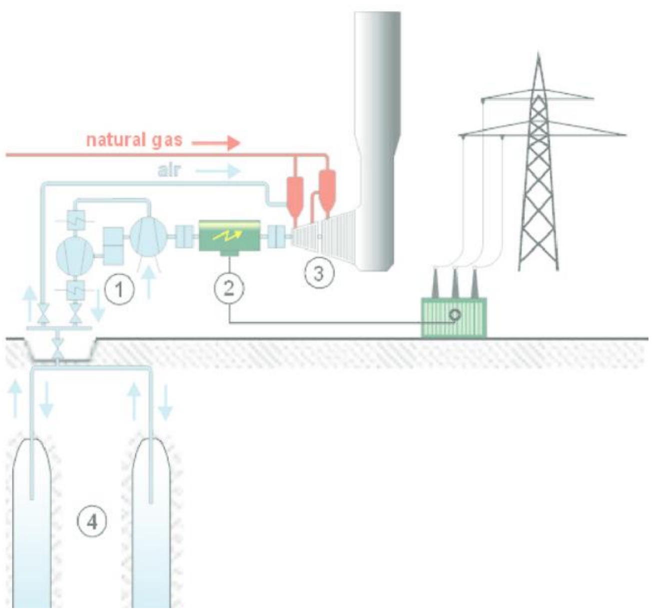


Figure 5 - Huntorf CAES system. Source: (Kuczyński, Skokowski, Wlodek, & Polański, 2015)

Figure 5 contains a schematic representation of the Huntorf CAES energy storage plant. Four main elements are numbered: 1: compressor, 2: generator, 3: gas turbine, 4: caverns.
The compressor stores the compressed air in the caverns. This air can be released into the gas turbine where it is used to burn gas, which powers the generator, generating electricity to deliver to the grid.

CEAS systems are suitable for large scale and long-term energy storage due to their high capacity and low self-discharge. The storage of pressurized air underground has little impact on the surface environment, however a CAES system still burns externally supplied gas in order to operate the combustion engine, so it still leaves a carbon footprint when in operation. Another disadvantage is the geographical limitations. The space needed to store compressed air is very large and therefore it is often stored in underground caves. Excavation work will be involved when constructing a CAES system and can be expensive.

3.1.3 Flywheel Energy Storage (FES)

FES uses spinning mass in a vacuum chamber to store energy as kinetic energy. During times of peak energy generation, the flywheel is accelerated, transferring electric energy to kinetic energy. When energy is needed, the spinning flywheel can accelerate an electrical generator which transfers kinetic energy back to electrical power. An example of FES is the flywheel in Stephentown, New York. It was built in 2009 and has a capacity of 20MW which can be delivered for 15 minutes (Kalaiselvam & Parameshwaran, 2014).

The speed of the spinning masses will drop quickly when not charged (about 20% of stored energy per hour) (Kalaiselvam & Parameshwaran, 2014; Gao, 2015). Because of these high self-discharge rates, FES systems are not suitable for long-term energy storage. They are however very suitable for short term energy storage because of the quick response time and high efficiency. These systems require precise engineering and are expensive to build.

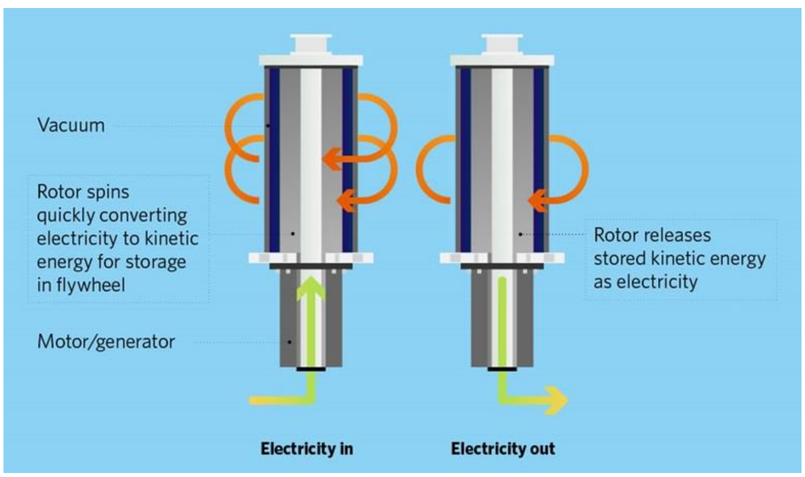


Figure 6 - FES system. Source: (IESO, 2017)

Thermal Energy storage

3.1.4 Thermal Energy Storage (TES)

TES is a technique where energy is stored by producing heat or cold. Air, liquids or solids can be heated during peak energy generation periods and this heat can be used to operate systems that generate energy from this heat during high demand or low generation periods. Energy stored in cold temperatures can be used for cooling applications. An example of a TES system is the heating accumulation tower from Theiss near Krems an der Donau in Lower Austria. It has a capacity of 2 GWh.

Several different technologies of TES exist. Some of them are very specific to a situation where heat or cold is generated in another process and this energy can be re-used in other ways (for example a data center that generates heat which can be used to heat nearby offices). For these technologies, desired temperatures (heat or cold) will be lost relatively quickly over time. Other technologies include hot water, molten salt, solid or liquid metals and ceramics. TES systems can store energy for days up to months, therefore suitable for long-term storage, however systems for long term storage generally require lot of space to store the materials used for energy storage (Shah, 2018). TES systems have a low efficiency compared to other systems. They be technically complex, which increases the costs on engineering. The costs for the materials are generally cheap (often water or salt).

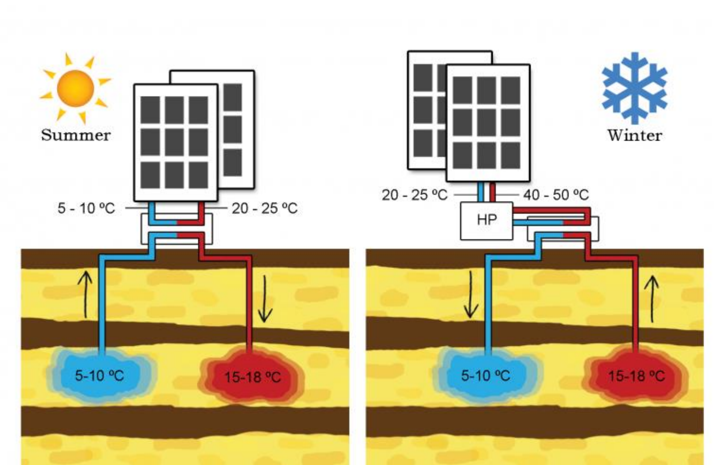


Figure 7 - TES system. Source: (Wassink, 2018)

Figure 7 shows an example of a thermo energy storage system. In the figure, a cold well (blue) and a warm well (red) are visible. Water from the cold well is pumped through a building during the summer to cool it down. The water will absorb the heat, after which it is pumped into the warm well. The warm water from the warm well is used to heat the building during the winter and is pumped into the cold well when it has cooled down.

Electrochemical Energy Storage

3.1.5 Hydrogen-based Energy Storage (HES)

The main principle of HES systems is a hydrogen fuel cell that uses electricity and water to produce hydrogen and oxygen. This electricity could be supplied during peak energy generation periods. The reverse reaction where hydrogen and oxygen generate water and electricity. This electricity can be delivered in high demand or low generation periods.

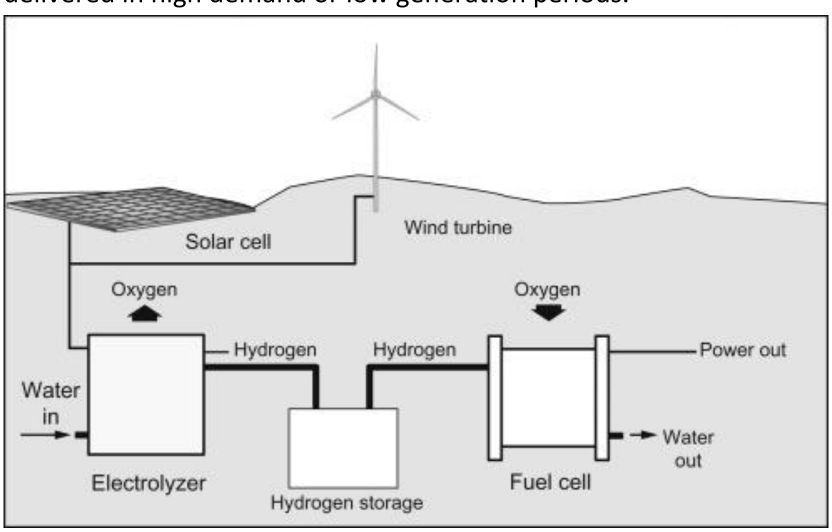


Figure 8 - HES system. Source: (Breeze, 2019)

Figure 8 shows a schematic representation of a HES system. In this illustration, power from solar panels and wind turbines powers an electrolyzer, which produces hydrogen. Hydrogen is stored and can be used in a fuel cell to generate power.

Currently HES technologies have a very low round-trip efficiency and are still expensive. A report of The Intergovernmental Panel on Climate Change mentions an efficiency of around 40% and mentions that this solution is not cost-effective (Pineda, Fraile, & Tardieu, 2018). Trainer also mentions that handling and transporting hydrogen can be problematic since it can easily leak, react with other elements and the costs of transportation of hydrogen is considerably high with regards to the energy gained from this hydrogen (Trainer, 2017).

Despite the disadvantages it might be a promising technology because of the high energy density. This technology is still experimented with in order to improve the performance of this technology (Kousksou, Bruel, Jamil, Rhafiki, & Zeraouli, 2014).

3.1.6 Electrochemical Battery Energy Storage (EBES)

Several different batteries are developed that use this technique, including lead-acid batteries, nickel-based batteries, sodium-sulfur batteries and lithium-based batteries. The main principle of this technique is that electrical energy can be stored by running this electrical energy through a battery which causes chemical reactions inside the battery. A battery can be discharged by connecting it to an external circuit, causing reverse chemical reactions inside the battery, releasing electrical energy. The main difference between different battery systems are the used materials, which determine its characteristics.

In the studied documents, several different technologies for EBES systems are described. These documents also mention that the main concerns about this technique are safety and lifetime. Electrochemical batteries may have high efficiencies, but they also have a short life time and a limited number of recharge cycles. Safety and environmental concerns play a big role since most of these batteries use toxic (often scarce) materials. Due to their high efficiency and high costs, this technology is commonly used on small scale, for example in mobile phones.

An example of storage for sustainable energy is the Tesla Powerwall. The Tesla Powerwall is a lithium-ion battery which has a capacity of 13.5 kWh, ad can deliver continuous power of 5kW (Tesla, 2019). It can be used to store energy generated during the day by solar panels on rooftops of houses and deliver this energy when the panels don't generate power.

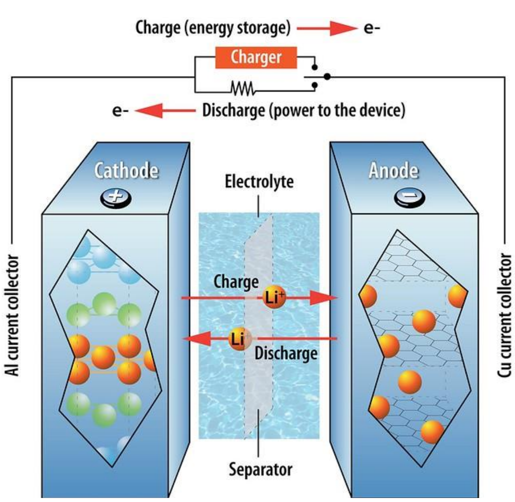


Figure 9 shows a schematic representation of a Lithium-Ion battery. During the charging process, lithium ions from the cathode and electrolyte are moving towards to the anode to obtain electrons and are reduced to lithium which are then embedded in the carbon material of the anode. During the discharging process, the embedded lithium from the anode loses ions and moves toward to the positive electrode.

Figure 9 - Lithium Ion energy storage. Source: (Argonne National Laboratory , n.d.)

3.1.7 Vanadium Redox flow batteries

The vanadium redox flow battery is a an electrochemical energy storage technology which has very less carbon footprint for electricity generation (Parasuraman, Lim, Menictas, & Skyllas-Kazacos, 2013).

It can store large scale of renewable and grid energy, like the energy produced by sunlight and wind (Li, et al., 2011). With this technology, the electrical energy will be converted to chemical energy and releases the energy from chemical energy to electrical energy when needed (Li, et al., 2011).

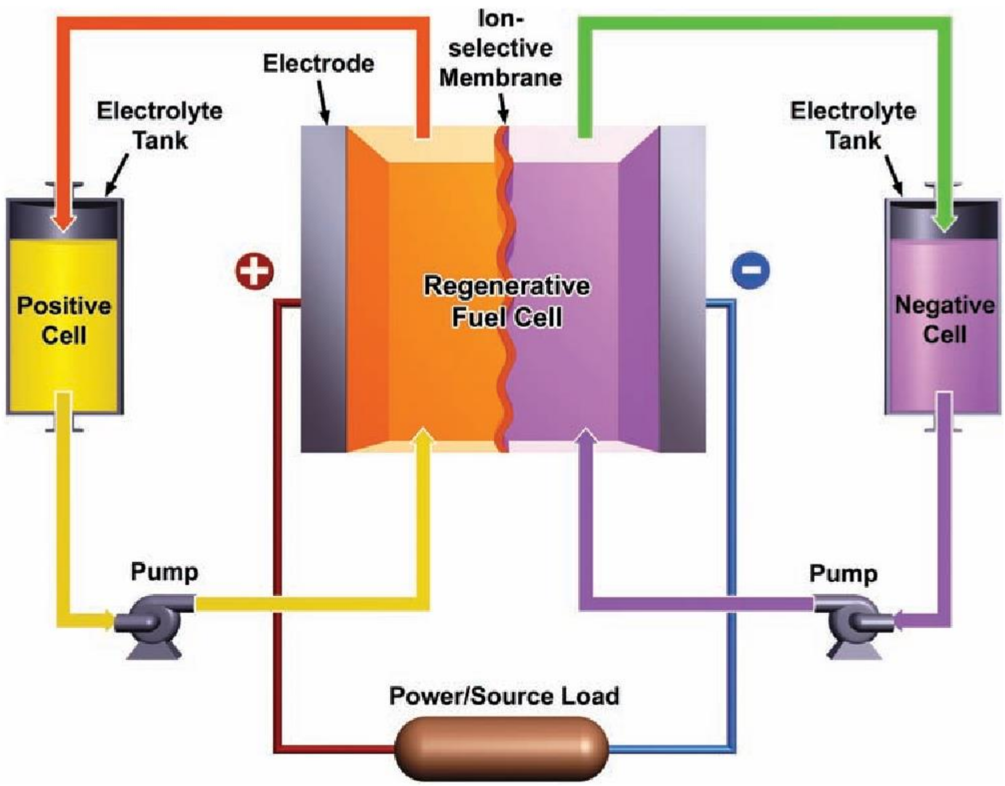


Figure 10 - Schematic representation of a vanadium redox flow battery. Source: (Li, et al., 2011)

As can be seen in Figure 10, a vanadium redox flow battery has two electrodes and two tanks of circulating electrolyte solutions which contain active species of vanadium in different valence states, one positive, one negative with one or more cell stacks between them (Xie, 2011). The solutions in the two tanks are pumped separately to the cell stacks while a thin ion-exchange membrane in the cell stack keeps the two solutions from mixing together (Li, et al., 2011). When the battery is being charged and discharged, the electrochemical half reactions of a vanadium redox flow battery are as follows (Alotto, Guarnieri, & Moro, 2014):

positive electrode

$$VO^{2+} + H_2O \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} VO_2^{+} + 2H^{+} + e^{-}$$

negative electrode

$$V^{3+} + e^{-} \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} V^{2+}$$

Examples of VRFB systems are the 10MW vanadium redox flow battery station in Zaoyang, Hubei province, China (China Energy Storage Alliance, 2018) and a project of a 200 MW installation that is currently still under construction in Dalian, Liaoning province, China. (Dalian Hengliu Energy Storage Power Station Co. & Shenyang Luheng Environmental Consulting Co., Ltd., 2016).

One of the key elements of this technology is vanadium. The main vanadium production countries are China, Russia, South Africa and Brazil. The respective production proportions in 2017 and 2018 were for China 56 percent and 54.8 percent, Russia 25 percent and 24.7 percent, South Africa 11.2 percent and 12.5 percent and for Brazil 7.2 percent and 8.6 percent (U.S. Geological Survey, 2019).

An advantage of the VRFB is the relatively high efficiency. Research has shown that the VRFB has a an efficiency of around 80 percent and the battery operating process was stable and reliable (Yang, Liao, Su, & Wang, 2013). In Table 1 can be seen that the efficiency ranges from 75 to 85, which is comparable to pumped hydro energy storage systems. In the VRFB, the main metal element which is used in the system is vanadium, so there will be no irreversible chemical reaction with other metal elements which makes sure there will be no cross -contamination in the electrolytes.

It also has some disadvantages, low energy density for instance. Currently researchers are focusing on electrolyte optimization, stack design optimization, membrane development and electrode development in order to improve efficiency and energy density (Parasuraman, Lim, Menictas, & Skyllas-Kazacos, 2013; Kyriakopoulos & Arabatzis, 2016).
Another disadvantage is the use of vanadium. The average vanadium pentoxide prices in 2018 almost doubled compared with the prices in 2017 (U.S. Geological Survey, 2019). The price of the VRFB will also be influenced by the vanadium market price.

3.1.8 Acid/base flow battery

The acid/base flow battery is an energy storage technology based on a reversible acid/base reaction. During the battery charge step, the electric power will be used for water dissociation to convert NaCl solution into NaOH and HCl. The opposite process, neutralizing the acid and base is the energy recovering process. During the charging and discharging processes, the following reactions can happen:

$$B + H_2O \leftrightarrow BH^+ + OH^-$$
$$BH^+ + H_2O \leftrightarrow B + H_3O^+$$

B is a neutral base, BH+ is the catalytic active center (normally the fixed charged group on the anion exchange membrane), A− the fixed group on the cation exchange membrane, and AH a neutral acid (van Egmond, et al., 2017).

$$A^- + H_2O \leftrightarrow AH + OH^-$$
$$AH + H_2O \leftrightarrow A^- + H_3O^+$$

As can be seen in Figure 11, part A, the reservoirs with different solutions (base, acid, salt, redox) are on the right side of the battery system where the energy is stored. On the left side is the membrane assembly, also called power unites. There are hundreds of membranes in a repetitive manner stacked between the two electrodes. In Figure 11, part B is a single cell's close up where the water dissociation process and mass transport happen(when it's charging). The discharge process of a cell, neutralization of the acid and base and mass transport can be seen in Figure 11 (van Egmond, et al., 2017; van Egmond W. J, 2018).

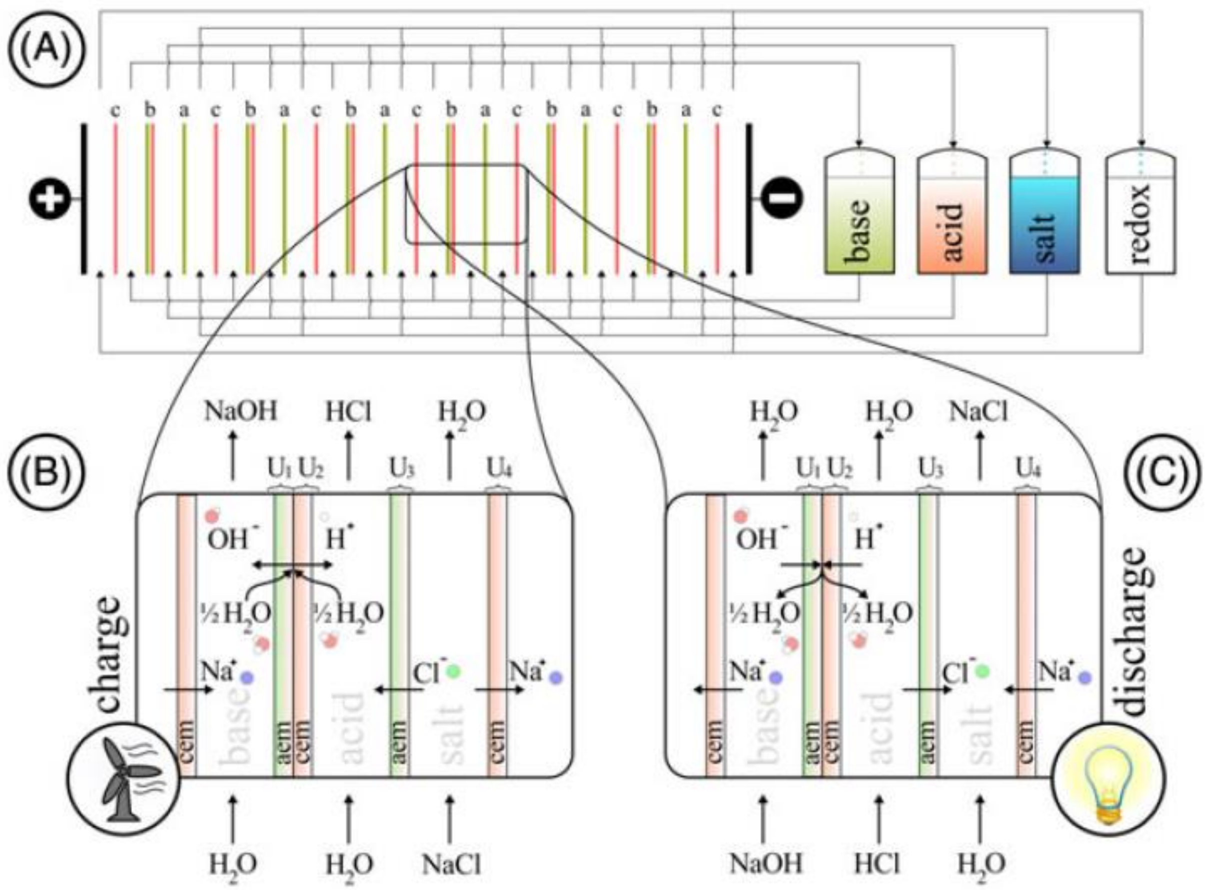


Figure 11 - Schematic representation of acid/base flow battery. Source: (van Egmond, et al., 2017)

The Blue acid/base battery is still in experimental phase and the energy density and especially the round-trip efficiency of this technology is still very low in comparison with other technologies.

The major advantages for this technology so far include safety and sustainability. The Blue acid/base battery does not involve exothermic reactions and is thermally stable. It does not use highly flammable substances, therefore the dangers in case of hazardous events are low.
This technology does not use scare materials, the main components of the acid/base flow battery system are water and salt. Because of these materials, the environmental impact is very low (Baobabproject - challenges, 2019). The NaCl solution can be taken from the battery and recycled back to the sea (van Egmond, et al., 2017).

3.2 Comparison of energy storage technologies

In this chapter several properties of different energy storage technologies are compared. These properties are:
Energy density, the amount of energy in W·h per kilogram of storage medium;
Capacity, the energy storage capacity of storage systems in MW, expressed as a range from lowest to highest recorded capacity;
Lifetime, the amount of years before a system reaches end-of-life;
Levelized costs of storage, a metric where the total costs of an energy storage system is spread out over its lifetime, including round trip efficiency, operational costs and charging costs (van Egmond W. , 2018);
Round trip efficiency, the percentage of energy that can be retrieved from the energy put in to that system.

The data for these properties has been gathered by studying different scientific studies on energy storage systems, combining similar information and recording the highest and lowest mentioned values in these papers.

Data sources: (van Egmond W. , 2018; Mahlia, Saktisahdan , Jannifar , Hasan , & Matseelar, 2014; Kyriakopoulos & Arabatzis, 2016; Kousksou, Bruel, Jamil, Rhafiki, & Zeraouli, 2014).

Table 1 - Comparison of energy storage technologies

Energy Storage Technology	**Energy density (Wh/kg)**	**Capacity (MW)**	**Lifetime (years)**	**Levelized cost of storage * (€ / kWh)**	**Round trip Efficiency (%)**	**Advantages**	**Disadvantages**	**Application level**
Pumped Hydro (PHES)	0.5 - 1.5	100 - 5000	30-60	0.12	75–85	High capacity Low costs per kW·h	Geographical restrictions Low energy density	Bulk storage Large scale (grid connected) Long term storage
Compressed air (CAES)	30 - 60	3 - 400	30-60	0.13-0.16	50 - 89	High capacity Low costs per kW·h	Contaminant emissions Geographical restrictions	Bulk storage Large scale (grid connected) Long term storage
Flywheel (FES)	30 - 100	0.25 - 20	15-20	-	90 - 95	High efficiency	Low capacity High discharge rate	Short term storage Small / Medium scale (cars, trains, space ships)

Thermo based (TBES)	80 - 250	0 - 300	5 - 40	-	30 - 60	High capacity High energy density Useful in specific situations where other processes generate or need heat or cold	High discharge rate Low efficiency	Medium to large scale (factories, steam engines) Short and long term storage
Hydrogen based (HBES)	70 - 270	-	5 - 15	0.42 – 0.48	48 - 69	Low environmental impact High energy density	Low efficiency High investment costs Highly flammable Transportation difficulties	Medium to large scale (cars, rockets, grid connected storage)
Electrochemical Li-ion Battery	75-200	0.1	5 - 15	0.62	85 - 98	High efficiency High energy Density	Short lifetime Environmental and safety concerns Limited thermal tolerance Thermal run-away	Small to large scale (household appliances to grid connected storage for wind farms) Short and long term storage
Vanadium Redox Flow Battery (VRFB)	10 - 50	0.3 - 15	5 - 15	0.35	75 - 85	High efficiency	Low energy density High costs Potential environmental danger	Small to large scale Long term storage
Acid/Base Flow Battery (ABFB)	2.9 currently 11.1 theoretically	1kw(pilot)	5 - 20 5-10 for membrane	0.26 – 0.44	13.5	Resources easy to obtain Low environmental impact Can be upscaled	Low energy density Low efficiency	Small to large scale Long term storage

3.3 Review of the comparison data

PHES. What stands out the most is the low energy density of this technology. This is due to the fact that this technology does not use chemicals or pressurized mediums to store energy, but purely water stored on a higher altitude that can flow through a generator. The next thing that stands out is that this technology has the highest capacity and the lowest costs. With a low energy density, the space needed to reach such high capacities is large. As mentioned in chapter 3.1.1, lakes are often used as storage. Natural lakes have already claimed their space and can often store large amounts of water, resulting in a high capacity. This technology has matured over time and has reached low costs. Except from the geographical limitations, this technology is suitable solution for long term, grid connected storage for sustainable energy due to the high capacity and low costs.

CEAS. This technology has a lifetime and costs comparable to PHES. However, no systems have built with capacities as high as existing PHES systems, the capacity and efficiency can be high enough to make this system suitable for long term grid connected storage of sustainable energy. In addition, this technology has a higher energy density compared to PHES because it uses compressed air.

FES systems are able to reach one of the highest efficiencies. As mentioned in chapter 3.1.3, the self-discharge is high, and this system is therefore useful for systems that charge and discharge rapidly (multiple times in an hour or day).

TBES systems can reach a high capacity comparable to CAES and high energy density comparable to HBES and Li-ion batteries, but have a low efficiency compared to the other technologies.

HBES systems have a high energy density, however the costs are still relatively high and efficiency is low (comparable to TBES systems). This technology is still experimented with and under development, so this might be improved in the future.

Li-ion batteries have a high energy density and high efficiency compared to other technologies. The costs of this technology is higher compared to other technologies. The high energy density allows for small size batteries with high capacity. Small size, high capacity and high costs makes this a favorable technology for small scale storage, for example household appliances or phones.

The VRFB has an efficiency comparable to PHES systems. The capacity, energy density, lifetime and costs are inferior to CEAS and TBES technologies, but VRFB has no geographical restrictions and has a higher efficiency than TBES systems.

Currently the ABFB still has a very low roundtrip efficiency compared to other storage technologies, but van Egmond mentions that significant improvements can be made in future experiments (van Egmond W. , 2018). Additionally, the current energy density of the ABFB is low compared to the VRFB. The theoretical energy density, still experimented with, is much closer to the VRFB.
The lifetime of the ABFB is comparable to that of the VRFB, Li-ion batteries and Hydrogen based storage systems. The levelized costs of the ABFB is comparable to that of the VRFB. However, the VRFB relies on vanadium resources and the price of this battery might fluctuate according to vanadium prices. The low environmental impact and the safety of the ABFB are the biggest advantages of this battery.

4 Niche marketing analysis

4.1 Introduction

Strategic niche management

Strategic Niche Management (SNM) is a concept or tool to support the societal introduction of innovations. (Geels, 2002).

A niche is defined as an upcoming, new technological innovation, culture or structure on a small scale (Coenen, 2018). Often niches are experiments, innovations in a protected environment (Geels, 2002). Regimes are defined as a very powerful social/political structure, culture, technology or rules on a large scale (Coenen, 2018). A niche can grow to a niche-regime, and finally become or take over a regime. Socio-technical regimes are defined as the dominant way in which social needs such as energy supply and mobility are fulfilled (Coenen, 2018).

Regimes have the characteristic of wanting to keep their power. There is often something in the current regime that makes it difficult for niches to break through, which include institutional, social and technological difficulties (Geels, 2002). These three categories are explained below.

- Institutional difficulties: regulations, institutions or administration are too rigid so it's hard to change anything there.
- Social difficulties: big organizations, networks etc. can be 'blind' for innovation because they're used to old systems and support those. They might not trust or believe in new ideas.
- Technological difficulties: current technology can be 'locked-in', which means that a technology in some way has become a standard in the market and it's hard to add something new or to change it.

SNM aims at experimenting with niches at small scale and attempts to tackle the following barriers for successful implementation of niches (Coenen, 2018):

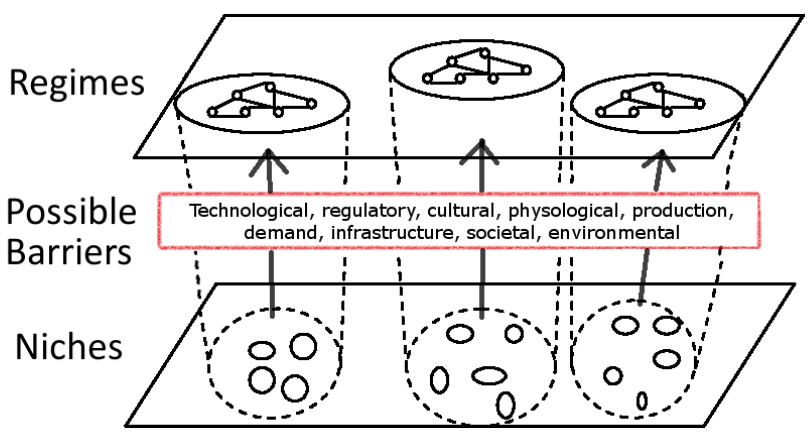


Figure 12 - Transition from niche to regime and possible barriers

• Technological barriers: the new technology might lack technical stability, does not perform sufficiently, or there is a lack of complementary technologies.

• Government policy and regulatory barriers: the new technology could not fit existing laws and regulations.

• Cultural and psychological barriers: the new technology could not fit user (or societal) preferences and values.

• Demand barriers: the new technology could not fit user demands (e.g. it is too expensive).

• Production barriers: the new technology could not fit expectations about what the user wants or the new technology is expected to compete with the core products from that company. Therefore companies are hesitating to take the new technology into large scale production.

• Infrastructure and maintenance barriers: there could not yet be an infrastructure or maintenance network.

• Undesirable societal and environmental effects: new technologies may solve problems but also introduce new ones.

Transition management

Another useful tool to bring a niche technology to the market is Transition Management.
Transition Management consists of four phases (Loorbach, 2007):

1. Strategic level: analysing the problem, research, create visions.

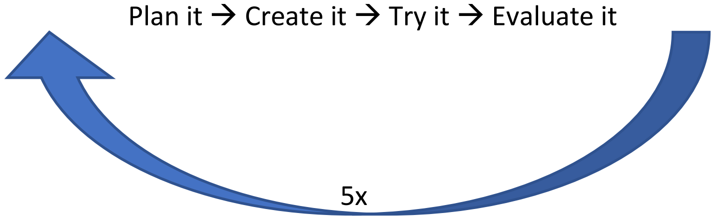
2. Tactical level: do the innovating, create new things to reach that goal, developing pathways.

3. Operational level: socio-technical scenarios, try niche in real life, see if it fits society, experiment.

4. Evaluation: determining effectiveness; maybe re-design and make changes if necessary.

According to Loorbach transition of a niche to the market needs an average of five rounds of these four phases.

Plan it → Create it → Try it → Evaluate it



Transition Management can be difficult, and it is good to learn from other projects. Rotmans mentions a few reasons why Transition Management has failed in the Netherlands:
- Transitions were hard because dominant regimes (government, industry) were blocking. They slowed down innovation and tried to block sudden changes.
- Not enough people participated in the project.
- Niches focused on the wrong scope, they focused on central changes, but they should’ve focused on local or regional innovations. Changes on small scale (e.g. local) are likelier to happen than changes at large scale (e.g. national).
- Budget cuts from government complicated the process.
- The focus was too much on technological innovations instead of social innovations.
(Rotmans, 2011).

4.2 Analysis

In the situation of BAoBaB project, the blue acid/base battery can be considered to be the niche. The current mature energy storage technologies can be labeled as regimes in this case. When trying to take over these current regimes, several difficulties may appear. These hinderances will be identified by analyzing the BAoBaB project using the tools Strategic Niche Management and Transition Management as mentioned in chapter 4.1. For Strategic Niche Management the difficulties mentioned by Geels and the possible barriers as mentioned by Coenen will be reviewed. For Transition Management the reasons for failure will be reviewed to see if these are possible pitfalls for the BAoBaB project.

Strategic niche management

The difficulties mentioned by Geels (explained in chapter 4.1) are institutional, social and technological difficulties.

Institutional difficulties

The European and Dutch governmental institutions do not seem to be a large difficulty. The EU and the Dutch government actively support the development and use of innovative and environmentally friendly energy storage systems which allows niches to develop.
In the Netherlands, power grids are owned by private companies (Overheid, Netcode elektriciteit, 2019). These network operators have their regulations and standards. When an energy storage system is connected to a power grid, they will have to comply with these operator specific rules, so this will be a point of attention. The same can be said for an energy storage system connected to the Chinese power grid, which is controlled by the Chinese government (Zhang, Tang, Niu, & Du, 2016). The Chinese government has detailed technical and non-technical specifications for energy storage systems connected to grids (see appendices 1, 2 and 3). This will require attention when upscaling in China.

Social difficulties

Regarding social hinderances, it is important to expose that, as expected, organizations don't tend to m immediately trust a specific (new) niche without transparent reports about efficiency and costs. After all, profit is the main goal of most organizations, and switching to a new energy storage system is an investment that is mostly only worth it when it could increase profit. As seen in Table 1 of chapter 3.2, the levelized costs of the ABFB are comparable to other technologies, but the efficiency and energy density of the ABFB are lower compared to others. If this is not improved, the market might tend to prefer other technologies over the ABFB.

Technological difficulties

Regarding possible technological threatens, some questions could be raised, namely: Hydro pumped energy storage systems in China could be replaced, but it would cause discussions about environmental passives caused by unutilized infra-structures. Such aspects brings the conclusion that, as long as the focus will rely on the need of energy storage, it could be difficult to compete with existing energy storage systems.

The possible barriers for successful implementation of a niche which SNM attempts to tackle as described by Coenen are: technological barriers, government policy and regulatory barriers, cultural and psychological barriers, demand barriers, production barriers, Infrastructure and maintenance barriers and undesirable societal and environmental effects (explanation of these categories in chapter 4.1).

Technological barriers

As concluded in chapter 3.3, efficiency is a major technological barrier for successful implementation of the Blue acid/base battery. Mainly because it is not (yet) able to compete with other (studied in this work) technologies. Dominant regimes (existing, mature energy storage technologies) might be favored over the Blue acid/base battery when those technologies store and deliver energy with higher efficiency.

<u>Government policy and regulatory barriers</u>
This category is similar to the category 'institutional difficulties' from Geels. Governmental policies and regulations (regulations from non-governmental organization as well) might be a barrier when the technology is not compliant. A more detailed vision about what are the main focus of such policies is presented in sequence, so the reader will be able to concretely picture possible (and current) challenges.

<u>Cultural and psychological barriers</u>
These barriers have yet to be identified, if at all existing. Based on the findings of the present study, there seems to be no personal or societal preferences or values that would limit the success of the BAoBaB project, i.e. for the studied regions (China and Netherlands). If, nevertheless, such barriers are still expected, it is advisable to consider the possibility of, while performing real-life experiments with the niche technology, societal values which might impose challenges for the implementation of the technology are included in the evaluated parameters.

<u>Demand barriers</u>
This can be partly related to the technological barriers. The user will demand a product with technical requirements that suits his wishes. Performing real-life experiments and engaging with possible users is a way to find out the users demands. As concluded in chapter 3.3, the efficiency of the niche technology is currently low, and this could be a barrier when users demand a higher efficiency. Additionally, the energy density of the battery is still lower when compared to existing systems. A low energy density means that the size of the battery should be relatively large in order to reach a sufficient capacity. This could be a barrier in situations where space is limited, for example when used in private homes.

<u>Production barriers</u>
No conflicting interests have been identified within the BAoBaB project since the Blue acid/base battery technology is the only technology that the BAoBaB project is focused on. However, the potential market could be very limited when demand barriers still exist, which will limit large scale production.

<u>Infrastructure and maintenance barriers</u>
Whether the infrastructure and maintenance network is sufficient depends on the specific situations. In technologically advanced areas these will be less of a barrier compared to undeveloped or remote areas. For example, in chapter 6.1, a case is described about energy storage on an Italian island. Islands can be remote areas without grid connection to the mainland. Another example is wind farms in Inner Mongolia, where the construction of the necessary transmission lines falls behind and is slowed down mainly due to uncertainties about the profits, resulting in a limited interest from the financial market (Zhang, Tang, Niu, & Du, 2016; Zeng, et al., 2014). It is good to analyze the infrastructure of an area where the niche will be marketed in order to identify infrastructure related hinderances.

<u>Undesirable societal and environmental effects</u>
This category includes new problems that appear after the niche has solved the problem that was intended to be solved. An unwanted effect in the case of new sustainable technologies can be problems with recycling of materials after the product has reached its end of life. An example of this are solar panels, of which recycling of end-of-life panels is not always thoroughly thought trough, causing unwanted environmental problems (Xu, Li, Tan, Peters, & Yang, 2018).

Transition management

Rotmans mentioned a few reasons for failure of Transition Management, including dominant regimes, lack of participation, wrong focus and budget cuts.
In case of the BAoBaB project, dominant regimes can be blocking. For example: companies that based their product or service on a certain technology might be 'locked-in', or users trust an existing technology more and lack the need to try a niche technology.

Lack of people participating does not seem to be a direct threat for failure since BAoBaB consists of many people from different countries and companies with different experiences. It is good however to not lose focus on participation and motivation of participants.
Governmental budget cuts might not be a direct threat since the project has already been fully funded by the EU. However, there are still steps to take in the transition from niche to regime (e.g. improving technology, market introduction, upscaling), and funds might become a difficulty when development of this technology is continued after the end date (30-04-2021) of this project, because however the EU has set environmental goals and is willing to support initiatives that contribute towards these goals, there is no guarantee that budget will be supplied by governmental bodies in the future. Even if funds will be supplied again, it is not a bad idea to compose a backup plan in case the project suffers budget cuts.

Success of a niche

Besides all these barriers and difficulties, Geels also describes the success of a niche in three stages (Geels, 2002):

1: Creating expectations and visions. This is necessary for attracting people, investors, and as guidelines to which goals you want to reach.

2: Build a social network. Social networks can be useful when the niche has to be brought to different fields, for example the scientific field or political field. Connections help to reach these fields.

3: Good learning moments. A niche should be something to learn from, not only on technological areas, but also on social, political, economic areas, etc. Niches should review themselves and should be willing to change according to what they learn in the meantime.

The BAoBaB project scores well on these three stages.
1: BAoBaB clearly creates expectations and visions and the goals of this project are clearly mentioned at their website. Their vision includes, but is not limited to: researching and developing a new, environment-friendly, cost-competitive, grid-scale energy storage for application at user premises or at substation level which can compete with pumped hydropower storage systems by obtaining energy conversion efficiencies of over 80% and >10 times higher energy density (Baobabproject, 2019).The project has also attracted investors: the EU has fully funded the project.
2: BAoBaB is a European collaborative project which consists of six partners from three countries: Wetsus, European Centre of Excellence for Sustainable Water Technology (NL), Università degli Studi di Palermo (IT), CIRCE: Centre of Research for Energy Resources and Consumption (ES), Fujifilm (NL), AquaBattery (NL) and S.MED.E Pantelleria S.p.A. (IT). These partners create a social network with expertise in different fields. This is useful when improving the niche technology (e.g. different views on how to improve on technical area) but also can be useful when introducing this niche to the market (e.g. a network of people who are willing to promote it, launch a pilot, etc.)
3: Learning and improving is essential for niches. The BAoBaB project aims on improving on technological areas which is made clear from their vision, which is *" to understand and enhance mass*

transfer in round-trip conversion techniques and hence to improve the energy conversion efficiencies of the BAoBaB system". Besides that, BAoBaB is also researching political and economic possibilities, where this research is an example of.

4.3 Conclusion

This chapter was focused on identifying the potential hindrances and niche strategies for developing the BAoBaB niche to a full-scale applied technology.

Governmental incentive to support BAoBaB does not seem to be a hinderance as the project is already funded by the European Union. The dependency on European funds is not necessarily a negative aspect, but it is a point of attention since there are still big steps to take and future funds might be a risk because budgets cuts have been a reason of failure for another project in the past. For future development and upscaling it might become a hinderance.

Social difficulties might also be a hinderance. It might be a challenge to introduce this battery in the market without creating trust in and motivation for this new technology. It is therefore good to not only focus on technological innovation, but also on social innovation. This can be done by using Strategic Niche Marketing as a niche strategy, which includes experimenting with the blue acid/base battery and put it to use in real-life environments on a small scale (e.g. local, regional). Conducting such an experiment should be used as a chance to identify and discover unknown barriers which SNM attempts to tackle (as mentioned in the introduction of this chapter).

The collaboration of six partners from three countries provides a good diversity of expertise. An addition to the niche strategy is to keep involvement and motivation of collaborators high, this will contribute to further success.

The barriers and hinderances discussed in this chapter were mostly focused on the niche project itself, however a potential hinderance that is not mentioned in this chapter yet are competing technologies. When other upcoming technologies become competitive even faster or become more competitive than the Blue acid/base battery, the market potential for the latter will decrease. It could also be that current regimes improve their technology, strengthening their market position. It is therefore good to keep an eye on the developments of upcoming and existing energy storage technologies to prevent unforeseen disadvantages.

5 To what extent do policies influence the market potential and occurrence of hindrances in the EU and China (for blue acid/base battery among its competitors)?

5.1 Relevant policies and standards related batteries similar to the blue acid/base battery in the EU and China

Since the Blue acid/base battery is not officially in the market yet, there is also no related policies or standards published related to this battery. In this chapter the policies and standards of the similar technology (vanadium redox flow battery) will be used as a baseline in order to analyze what could be the related policies and standards for the Blue acid/base battery.

5.2 Emission standards of pollutants

China, EU and the Netherlands all have specific requirements and standards about water and air pollutant limits for industry areas. China specially made one emission standard for the battery industry, GB30484-2013. All the limits are mentioned in the standards, for example, for air pollutant emission limits, the limit for sulfuric acid mist is maximum 0.3 mg/m^3, hydrogen chloride 0.15 mg/m^3; for water pollutant emission limits, the pH should be between 6-9, COD 70---). The Netherlands follows the requirements from the EU directive 2008/1/EC, “Concerning integrated pollution prevention and control”. In this document, all the related aspects are mentioned, including COD, BOD, suspended matter for water pollutant emission. However, the specific numbers cannot be found in EU directive, it only provides guidelines on pollution prevention and control. In the Dutch law on environment management (Activiteitenbesluit milieubeheer), some specific numbers for emission limits are given, for example: the limit of 35mg/Nm^3 is mentioned for SO_2 air emission and 80mg/Nm^3 is given as a maximum for the Nitrogen oxides emission.

The specific requirements comparison between China, EU and the Netherlands can be seen in the appendix 1. The fact that fewer indicators were collected in China’s standards could be that the Chinese document used for this analysis are specifically for the battery industry but the documents from the EU and the Netherlands are for multiple industries.

5.3 Treatment methods for waste batteries in different areas

Table 2 - Waste treatment methods

Battery waste treatments approaches (from all kinds of batteries)	**China**	**EU**	**TNL**
Collecting the waste batteries		2006/66/EC	BWBR0024492 2006/66/EC
Collecting conducted by Manufacturer, Importer and Manufacturer who’s product contains the battery.	√	√	√
Collecting conducted by the government			
Cooperation between government and enterprise (re-use in another area)	√		

Batteries collecting conducted by the third party	√	√	√
2. Battery waste treatment		2006/66/EC	BWBR0024492 2006/66/EC
Self treatment (Manufacturer, Importer and Manufacturer who's pr oduct contains the battery)		√	√
Third party treatment	√	√	√
Combination of self and third party treatment		√	√

The table above shows the waste battery treatment in different areas. In the EU and the Netherlands, waste battery collecting should be taken care of by the manufacturer or importer of batteries, or the manufacturer whose products contain batteries. China has the same rule. However, in this country the government can cooperate with companies to facilitate recycling waste batteries that are still functional reused and apply them in other areas after reparation. For example: the waste batteries from electric cars can be reused for stationary applications such as car charging stations or grid connected energy storage (Casals, García, & Canal, 2019).

For the waste battery treatment, both the EU and the Netherlands allow third party treatment, self-treatment by the manufacturer and a combination of self and third-party treatment. In China however, some waste batteries (e.g. waste vanadium redox flow batteries) are considered as dangerous wastes and can only be treated by a third party which is a company or organization specialized in dangerous waste treatment. Before sending the waste batteries to this third party, producers of hazardous waste should follow the standards for pollution control on hazardous waste storage standard (Chinese standard number: GB18597-2001).

In standard WB/T 1061-2016 from the Chinese government, more details about collection, transportation and storage of waste batteries can be found. In this standard, batteries are categorized as normal or dangerous batteries. The standards for identifying the appropriate category for a battery can be found in "Identification standards for hazardous wastes". These standards are presented in a series of seven documents with serial number 'GB 5085.X-2007', where X is a number from 1 to 7.

For both waste battery collection and treatment, the EU published the directive 2006/66/EC. The Netherlands has published a regulation on battery management "Regeling beheer batterijen en accu's" (Overheid, 2017) following directive 2006/66/EC from the EU. In this regulation, general guidelines related to battery collection and treatment are provided. Additionally, a form is included in this regulation that companies should report on a yearly basis to the government about their implementations of the regulations.

5.4 Technique rules for electrochemical energy storage systems connected to the power grid

China has very specific and detailed standards for electrochemical energy storage systems connected to the power grid. These standards are provided in GB/T 36547-2018. This standard includes details about for example requirements for grounding methods, harmonic requirements, power quality tests and automatic protection and safety device tests. The power grids in China are controlled by the government (Zhang, Tang, Niu, & Du, 2016), this could explain why these standards are detailed and openly published.

The Dutch regulations on power grids (Overheid, Netcode elektriciteit, 2019;Overheid, Elektriciteitswet 1998, 2019) provide generic statements about network regulations. The power grids are controlled and owned by private organizations, the network operators (Overheid, Netcode elektriciteit, 2019). ACM (Autoriteit Consument en Markt) is an organization in the Netherlands that supervises the energy market. The responsibilities and obligations of this organization are mentioned in the Dutch electricity regulation (Overheid, Elektriciteitswet 1998, 2019). One of the main tasks of ACM is monitoring the network operators. Details about electrochemical energy storage systems connected to the grid are not mentioned in these regulations, most of the technical details will depend on the different grid operators.

5.5 Electrolyte for VRFB

5.5.1 Product classification

The Chinese government has published a detailed standard for electrolyte for vanadium redox flow batteries. Batteries are sorted in three categories according to different valences of vanadium ions: trivalent electrolyte, 3.5-valent electrolyte, tetravalent electrolyte. Batteries are divided into first class and second class products according to their quality.

5.5.2 Main chemical content

The vanadium content, sulfate content, and ratio of vanadium ions in different valence states in the product should meet the requirements in the table.

Table 3 – VRFB electrolyte chemical content requirements

Product valences	**Components**		**Allowable deviation**
Trivalent electrolyte	V	≥ 1.50 mol/L	± 0.05 mol/L
	SO_4^{2-}	≥ 2.30 mol/L	± 0.10 mol/L
	V^{3+} : V	≥ 0.95	-
3.5-valent electrolyte	V	≥ 1.50 mol/L	± 0.05 mol/L
	SO_4^{2-}	≥ 2.30 mol/L	± 0.10 mol/L
	V^{3+} : VO^{2+}	1.0	± 0.10
Tetravalent electrolyte	V	≥ 1.50 mol/L	± 0.05 mol/L
	SO_4^{2-}	≥ 2.30 mol/L	± 0.10 mol/L
	VO^{2+} : V	≥ 0.95	

5.5.3 Impurity element content

The impurity in the products should meet the requirements in the table in order to be categorized in the corresponding class.

Table 4 - VRFB electrolyte impurity contents

Impurity elements	First class limits (mg/L)	Second class limits (mg/L)
Al	50	80
As	1	1
Au	1	1
Ca	30	70
Cl	100	-
Cr	15	30
Cu	1	5
Fe	50	200
K	100	200
Mg	30	50
Mn	5	30
Mo	20	30
NH_4^+	20	50
Na	80	200
Ni	20	60
Pd	1	1
Pt	1	1
Si	10	-

in this standards document are more details about the requirements of other aspects, for example the additive, insoluble impurities and the inspection rules of the products. More details can be found in document GB/T37204-2018.

Similar standards for electrolyte for vanadium redox flow batteries have not been found in this research.

5.6 VRFB test mode

The Chinese government has established detailed test plans containing 14 performance tests and five safety tests. These test plans are described in document GB/T 33339-2016 and for each plan is described which steps need to be taken, under which conditions the plan has to be executed and if necessary which formulas need to be used for calculating results.

Table 5 - 14 performance tests for VRFB

Performance tests	Safety tests
Stack consistency test	Overcharge test
Rated power test	Overdischarge test
Maximum discharge power test	Flame retardant performance test
Maximum charging power test	Hydrogen leak test
Rated watt hour capacity test	Insulation resistance test
Maximum watt hour capacity test	
Rated energy efficiency test	
Capacity retention test	
Low temperature storage performance test	
High temperature storage performance test	
Overload capability test	

State parameter accuracy test
SOC accuracy test
Protection function test

To the knowledge of the researchers, standards or test plans for VRFB from the EU and the Dutch government could not be found. However, an organization in the Netherlands called NEN (Nederlands Normalisatie-instituut) has established performance, safety and test requirements that can be purchased from their website (NEN, n.d.).

5.7 Technical regulations for safety and hygiene for vanadium redox flow battery energy storage power stations

A document containing technical regulations for safety and hygiene for vanadium redox flow battery energy storage power stations (NB/T XXXXX-2019) has been released by the Chinese government in 2019 as a draft that is open for comments. Some examples of the requirements:

- The power station site selection and station layout: locations and areas with direct damage such as mudslides, quicksand, severe landslides and caves cannot be selected as energy storage station sites.
- Building requirements: between the energy storage battery room and other equipment rooms, a non-combustible body wall with a fire resistance of not less than 3.0 h shall be used.
- Equipment operating safety: a maintenance channel shall be provided on one side of the stack frame and its width shall not be less than 1200 mm.

5.8 Policies related to energy storage systems

In order to introduce new energy storage technologies to the market, it can be useful that governments support this. China, the EU and the Netherlands all have policies which promote sustainable energy storage products and have a positive attitude towards developing new energy storage technologies. The European Union has completely funded the BAoBaB projects under a framework called Horizon 2020 which aims on promoting innovation in batteries (Baobabproject, 2019) , (European Comission, n.d.). The Netherlands promote the use of energy efficient and sustainable energy storage systems by providing tax reductions (RVO, 2019). The redox flow battery is specifically mentioned as a technology that is eligible for tax discounts. Since the technology of the ABFB is similar a redox flow battery, it is likely that users of the ABFB are eligible for tax discounts.
China encourages the cooperation between sustainable energy generation plants and energy storage systems (Chinese Government, 2017). The Chinese government has a policy that sets vanadium redox flow batteries free from import consumption fees (Ministry of Ecology and Environment, 2015). Which might also be the case for ABFB, since the technology is similar to the vanadium redox flow battery.

5.9 Conclusion

The research question for this chapter was: “To what extent do policies influence the market potential and occurrence of hindrances in the EU and China?”.

Both the Netherlands and China have emission standards of pollutants and waste treatment standards. In addition, China has specific emission standards for the battery industry and specific standards for the

Vanadium redox flow battery (e.g. Electrolyte for VRFB and VRFB test mode) while in the Netherlands and the EU emission standards can only be found for general types of industries and no public standards for the Vanadium redox flow battery have been found. Grid connection standards are also publicly accessible in China as the energy grids are controlled by the Chinese governments. This also implies that the government is responsible to control and publish the standards. In the Netherlands, the grid connection rules do not have an open access, and it is believed that this is due the fact that energy grids are privately owned by different network operators. These network operators maintain the grid connection regulations, which can differ between operators.

The European, Dutch and Chinese governments have a positive attitude towards sustainable and innovative energy storage systems and provide funds and subsidies in order to promote the development and the use of these systems. The tax discounts provided by the Dutch government and the exemption from import consumption tax in China are related to vanadium redox flow batteries and will possibly also apply to the blue acid/base battery. To be certain of these possibilities, this should be further investigated by contacting governments or official organizations like the ACM. This would probably not cause a negatively influence on the BAoBaB project, however, it also does not give an advantage over other innovative, sustainable energy storage technologies.

In conclusion, the encountered regulations and policies do not seem to cause significant hindrances but neither provide an advantage in the market, except the tax discounts that could provide an advantage over technologies that do not apply. The existing emission standards of pollutants, waste treatment standards, grid connection rules, and safety and hygiene standards as mentioned throughout this chapter can be used as a reference for the future development and application of the Blue acid/base battery.

6 Under which conditions can the blue acid/base battery be competitive

The blue acid/base battery is an environmentally friendly solution for energy storage, and under certain conditions it could be competitive on the energy storage market. The conditions will be illustrated through three different cases in which the Blue acid/base battery could potentially be used.

6.1 Potential cases

Wind farms in China

The rapid development of China's economy has caused serious impacts on the environment. The rapid growth of cities and industries and the use of fossil fuels on large scale to generate energy the necessary energy have caused deterioration of ecosystems and an increase in animals that face extinction, (National Environmental Protection Agency, 2015).

China has taken several actions in order to improve the declining situation. Several laws have been passed, (the Wildlife Conservation Law for example) and as a response to these laws, China has established plans that focus on improvement of biodiversity (National Environmental Protection Agency, 2016).

China's government has prioritized the replacement of existing fossil fuel energy sources with renewable energy sources. China has established the Renewable Energy Law in 2006 and has put development of sustainable energy and protection of ecosystems on their five-year plan. Since 1986 has been developing wind power farms, but the total installed capacity of wind energy has especially increased rapidly between 2005 and 2015 (Zhang et al., 2014) due to China's national plan for wind energy development (Management Office of RED programme, 2014).

Inner Mongolia is China's largest area for wind power generation because of the open grasslands on high altitudes with low vegetation (Zhang, Tang, Niu, & Du, 2016). Even though the wind farms in northern China produce a considerable amount of energy, part of this energy is rejected by the grid (in other words, this generated energy is wasted) (Zhang, Tang, Niu, & Du, 2016). This is mostly due to the fact that existing transmission lines cannot handle the amount of energy generated by the wind farms but also due to the mismatch between supply and demand (Zhang, Tang, Niu, & Du, 2016). The local demand near the wind farms is not high enough to consume the produced energy and therefore, this excessive energy goes to waste (Zhang, Tang, Niu, & Du, 2016).

Wind farms in China can be potential market where the blue acid/base battery can be competitive if the battery meets the condition of high capacity. With wind farms having a capacity ranging from 50 - 500 MW and a rejection rates ranging from 4.3 - 47% (Zhang, Tang, Niu, & Du, 2016), a possible battery installation that could store the rejected energy should have a capacity ranging from 2.15 – 235 MW (possibly connecting multiple batteries together).

Energy storage on islands

In the EU there are still many islands that depend on import of fossil fuels for their energy supply and they are not connected to mainland energy grids. The EU has started a Clean Energy for EU Islands initiative, a project to help islands with their transition to clean energy. These islands often have available renewable resources including wind, sunshine and waves (European Comission, 2019).
On some islands, solar panels have already been installed to generate energy. However, during the summer, the energy consumption is much higher than in the winter, mainly due to the tourists visiting in the summer. A case from Ginostra, Italy, shows that the amount of solar panels installed were matched with the summer energy requirements, when the population is significantly higher (Ciriminna, Pagliaro, Meneguzzo, & Pecoraino, 2016). This caused excess production of energy in non-tourist periods from October to May.

A seasonal energy storage solution could store the energy generated in periods of low tourism and deliver this energy in periods of high demand.
One of the conditions that needs to be fulfilled in this case, is that a battery should be able to store energy for several months. Another point of attention is that space on islands could be limited, so not too many geographical restrictions could be an advantage.

Solar panels in the Netherlands

The Netherlands has and still is developing wind farms in the North Sea. These wind farms range from 108 – 4000 MW (Rijksoverheid, n.d.) and could be a potential market for the blue/acid base battery, however nothing is known about the rejection rate. Besides the wind farms in the North Sea, the Netherlands has another market that could potentially be interesting. This market is the market of home batteries. According to an article published on the 26th of march 2019 from the Dutch Central Bureau of Statistics (CBS) the capacity of solar panels installed on roofs of houses increased by 37% between 2017 and 2018 (CBS, 2019). Currently, the Netherlands knows a regulation called 'salderingsregeling', which states that excess energy generated by households can and which was delivered to the grid, should be deducted from the amount of energy 'bought' from the grid. With this regulation, it is not profitable to invest in a battery that stores energy, instead it is more profitable to deliver it back to the grid. However, the Dutch government allows this regulation until 2023, after which the intention is to reduce this regulation, eventually resulting in zero compensation for excess energy (Rijksoverheid, 2019). In this situation, it might be a profitable solution to install a battery in houses in order to store excess energy for later use.

There are however competitors for home batteries, the Tesla Powerwall for example. According to the specifications provided by tesla, it has a usable capacity of 13.5 kWh, a round-trip efficiency of 90%, peak power of 7kW and a continuous power of 5kW. It has operating temperature from -20°C to 50°C weighs 114 kg and can be upscaled by connecting up to 10 Powerwalls to each other (Tesla, 2019).

The blue acid/base battery could be competitive in this case if it can fulfill certain conditions.
- Lifetime. The battery should have a long lifetime, where long could be defined as the time it would take to earn back the costs of the battery. Which also leads to a second condition:
- Costs. The price of the blue acid/base battery should be competitive with existing technologies. The costs for Tesla's battery for home usage for example are around €6500,- (Tesla, 2019).
- Efficiency. The battery should have a high round-trip efficiency. As mentioned above , the Tesla

Powerwall claims to have a roundtrip efficiency of 90%. Users might favor a high efficient battery over a less efficient one to achieve the lowest amount of energy loss. The roundtrip efficiency of the Blue acid/base battery is currently still very low, but Van Egmond suggests technical solutions that have potential for significantly improving the round trip efficiency. These solutions might be worth looking into in order to compete with other technologies.
- Safety. The battery should be safe, accidents in residential areas can give a company a bad name and can be disastrous for business.
- Size. The size of the battery should be suitable for a regular house. The energy density is of influence here. When the energy density is higher, it could have a smaller size compared to a similar battery with the same capacity but a lower energy density. A small size could increase the advantage of a battery for homes. It could fit in more places and could be easier to transport and install.
- Scalability. Modern, well isolated houses with a household of 1 person will consume less energy compared to a poorly isolated house with a household of 8 family members, or small businesses or hotels. Scalability means the flexibility in battery capacity to match the customers' needs.

7 Discussion and recommendations

The main research question addressed by this paper has been formulated as follows: “What are the market potentials and hindrances of the blue acid/base battery in EU and China?”.

This question has been divided by four sub-questions which are discussed in detail throughout this paper. These sub-questions will be summarized briefly and together provide an answer to the main question.

7.1 What are the characteristics of the blue acid/base battery and competing technologies?

The Blue acid/base battery is an energy storage technology comparable to the Vanadium Redox Flow battery. The environmental impact and possible dangers of this battery are considered by these authors as low, because water and salt are the main components. The high safety and low environmental impact of these batteries might be their strongest points. However, points like efficiency, energy density and capacity are less promising when compared to competing technologies.

7.2 To what extent do policies influence the market potential and occurrence of hindrances in the EU and China?

The policies reviewed in this research exist of governmental funds, tax discounts and subsidies. These policies have a positive influence on the development of the Blue acid/base battery, but also for other environmentally friendly energy storage solutions.
Existing regulations and standards do not seem to cause hindrances, instead they should be used as guidelines to avoid future ones.

7.3 What could be the potential hindrances and niche strategies for developing the battery to a full-scale applied technology in the EU and China?

Social aspects might cause potential hindrances for the Blue acid/base battery specially when considered immediate acceptance of unknown systems. Therefore it is advisable to include the social acceptance aspect as an analyzed variable when using techniques like “Strategic Niche Management. The diversity within the organization is an advantage that will contribute to the success of this project when continued to be used well.
Governmental budget cuts are a point of attention for the future, since it has been a reason for failure for other projects in the past. A possible mitigation action in this case is to carefully study long term innovation plans and strategies which are normally presented by governments.

7.4 Under which conditions can the blue acid/base flow battery be competitive?

Potential applications for this battery can be grid connected energy storage and household energy storage. When used as grid connected storage, it needs to fulfill the condition of a high capacity. High efficiency is also advised to reduce the loss of sustainable generated energy. When used as household energy storage, the efficiency should be improved drastically in order to be competitive with other energy storage technologies. Without high efficiency, this battery will waste lot of energy harvested from sustainable resources. The battery should also meet the conditions for a suitable size for houses.

8 Ethical statement

In this chapter several ethical concerns are covered.

Informed consent. Anyone participating in this research will receive a clear explanation of what the research is about and how they are involved. If they are willing to take part they must confirm this in writing or in some other recorded form. Participants have the right to withdraw their consent at any time.

Anonymity. Anyone participating in this research has the right to remain anonymous. By confirming to participate in this research, participants will not be held anonymous by default, unless the option to remain anonymous is chosen. This option will be given to participants when recording their confirmation of participation.

Quality, integrity and independency. To ensure the quality, integrity and independency of this research, it will be under review of Supervisors Dr. K. Lulofs, Dr. F. Coenen, Dr. L. Agostinho and Dr. M. Tedesco. Choices and conclusions made in this researched will be made with the best effort to be unbiased.

Sensitive data. To avoid that any sensitive data related to the research object is published which should have been kept confidential, the research needs approval of the company supervisor.

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10 Appendices

10.1 Appendix 1: Policy comparison form

1. **Emission standards of Pollutants** All the criteria of pollutant emission which is required from different regions can be seen in the standard 1.	GB 30484-2013 Emission standards of pollutants for battery industry	DIRECTIVE 2008/1/EC https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:024:0008:0029:EN:PDF	https://wetten.overheid.nl/BWBR0022762/2019-07-01/#Hoofdstuk5
(1) Air pollutant emission limits mg/m3	GB 30484-2013		BWBR0022762
① Sulfuric acid mist*	√ 0.3	√	
② So2			35mg/Nm3
③ Lead and its compounds	√ 0.001	√	
④ Mercury and its compounds	√ 0.00005	√	2-5ug/Nm3 according to different industries
⑤ Cadmium and its compounds	√ 0.000005	√	
⑥ Nickel and its compounds	√ 0.02	√	
⑦ Asphalt smoke	√		
⑧ Fluoride	√ 0.02	√	
⑨ Hydrogen chloride	√ 0.15	√	3-15mg/Nm3 according to different industries
⑩ Chlorine gas	√ 0.02	√	1/2mg/Nm3 according to different industries
11 Chlorine			3mg/Nm3 Avr/day 40mg/Nm3 moment
12 Nitrogen oxides	√ 0.12	√	80mg/Nm3
13 Ammonia			5mg/Nm3
14 Non-methane total hydrocarbon	√ 0.3	√	
15 Organic carbon			12mg/Nm3
16 particulates	√ 2.0	√	
17 Asbestos		√	
18 Carbon monoxide		√	100mg/Nm3
19 Volatile organic compounds		√	
20 Metals and its compounds		√	
21 Arsenic and its compounds		√	
22 Cyanide		√	

23 Substances with carcinogenic properties or properties which may affect reproduction via air		√	
24 Polychlorinated dibenzodioxins and polychlorinated dibenzofurans		√	
(2) Water pollutant emission limits	GB 30484-2013		BWBR0022762
① pH value	√ 6-9		
② COD	√ 70	√	
③ BOD		√	
④ Suspended matter	√ 50	√	√
⑤ Total phosphorus	√ 0.5	√	
⑥ Total nitrogen	√ 15		
⑦ Ammonia nitrogen	√ 10		
⑧ Fluoride(counted in F)	√ 8.0		25mg/l
⑨ Total zinc	√ 1.5		√ 0.2mg/l
⑩ Total manganese	√ 1.5		
11 Total mercury	√ 0.005	√	√ 3 μ g/l
12 Total silver	√ 0.2		
13 Total lead	√ 0.5	√	√ 20 μ g/l BWBR0022762
14 Total cadmium	√ 0.02/0.05	√	√ 5 μ g/l
15 Total nickel	√ 0.05		√ 50 μ g/l
16 Total cobalt	√ 0.1		
17 TOC (total organic carbon)			50 mg/l
18 Chromium			50 μ g/l
19 Copper			50 μ g/l
20 Sulfate SO42-			2g/l not for seawater or saline water
21 Sulfide S2-			0.2mg/l
22 Sulfite SO32-			20mg/l
23 Unit product standard displacement	√		
24 Special discharge limits for water pollutants according to the local situation	√		
25 Environmental protection authorities will conduct environmental monitoring	√		
26 Gas collection system, centralized purification treatment device and exhaust pipe where air pollutant is produced	√		
27 Organohalogen compounds		√	
28 Organotin compounds		√	
29 Substances with carcinogenic properties or properties which may affect reproduction via air		√	
30 Persistent hydrocarbons and persistent bioaccumulable organice toxic substances		√	
31 Cyanides		√	

32 Metals and their compounds		√	
33 Arsenic and its compounds		√	50 μ g/l
34 Biocides and plant health products		√	
35 Substances which contributes to eutrophication(in particular, nitrates and phosphates)		√	

10.2 Appendix 2: Vanadium flow battery system - Test mode

1. Scope

This standard specifies the terms and definitions, test items, test preparation, test conditions, measuring instruments and test methods of the measuring aspects of vanadium redox flow battery systems (referred to as battery systems).

This standard applies to scales and applications of the battery systems.

This standard does not cover electromagnetic compatibility (EMC) tests.

2. Terms and definitions

(1) Vanadium flow battery; VFB

An energy storage system works through the electrochemical reaction of different valence vanadium ions in the positive and negative electrolytes to achieve the conversion between electrical energy and chemical energy. Also known as the all-vanadium flow battery system.

Note: All vanadium redox flow batteries are mainly composed of power units (stacks or modules), energy storage units (electrolyte and storage tanks), electrolyte delivery units (pipes, valves, pumps, heat exchangers, etc.) and battery management systems. Part of the composition. [GB/T 29840-2013. Definition 2.1]

(2) State of charge; SOC

The ratio of the actual (remaining) watt-hour capacity that can be discharged to the maximum watt-hour capacity that can be discharged. [GB/T 29840-2013 definition 2.22.4]

3. Test items

Table 1 shows the performance tests and safety test items associated with the battery system.

Table 1 Test items and test classification

No.	**performance**	**Safety**
1	Stack consistency test	Overcharge test
2	Rated power test	Overdischarge test
3	Maximum discharge power test	Flame retardant performance test
4	Maximum charging power test	Hydrogen leak test
5	Rated watt hour capacity test	Insulation resistance test
6	Maximum watt hour capacity test	-
7	Rated energy efficiency test	-
8	Capacity retention test	-
9	Low temperature storage performance test	-
10	High temperature storage performance test	-

11	Overload capability test	-
12	State parameter accuracy test	-
13	SOC accuracy test	-
14	protection function test	-

4. test preparation

(1) Overview

For each test, the appropriate measuring instruments and equipment should be selected and a pilot plan should be made to minimize uncertainties. The test parties shall formulate a written test plan based on this standard. The following items shall be included in the test plan;

a) purpose;

b) test specifications;

c) test personnel qualifications;

d) The uncertainty of the results is in accordance with ISO/IEC Guide 98-3;

e) the requirements for measuring instruments and equipment;

f) the estimation of the range of test parameters;

g) Data collection plan (in accordance with the requirements of 5.2).

(2) Data collection and recording

In order to meet the target error requirements, the data acquisition system and data recording equipment should meet the needs of acquisition frequency and acquisition speed, and its performance should be better than the tested equipment.

5. Test conditions

Unless otherwise required, the test shall be carried out under the test conditions specified in this standard:

Ambient temperature: 25 °C ± 5 °C;

Air humidity: 5%~95%;

electrolyte temperature: 30 C±5°C.

6. Measuring instruments

(1) Overview

The measuring instrument shall be qualified according to the relevant national metrological inspection regulations or relevant standards and within the validity period, and shall meet the measurement accuracy specifications specified by the manufacturer.

(2) Electrical measurements

① Meter Range

The range of the meter used should be determined by the measured magnitude of the current and voltage. That is, the reading should be within the last third of the range.

② Voltage measurement

The meter for measuring voltage should be a voltmeter with an accuracy of not less than 0.5, and its internal resistance is at least 1kΩ/V.

Note: Other measuring instruments with the same accuracy can also be used with the voltage measurement mentioned above.

③ Current measurement

The meter that measures the current should be an ammeter with an accuracy of not less than 0.5. Note: Other measuring instruments with the same accuracy can also be used with the current measurement mentioned above.

④ Energy measurement

The meter for measuring electrical energy should be an electric energy measuring instrument with an accuracy of not less than 0.5.

(3) Temperature measurement

The thermometer for measuring temperature should have an appropriate range, the division value is not more than 1 ° C, and the calibration accuracy should be no less than 0.5 ° C.

(4) Time measurement

The meter for measuring time shall be indexed in hours, minutes and seconds with an accuracy of not less than ±1 s/h.

(5) Signal measurement

The meter that measures signal changes should be an oscilloscope with a bandwidth of at least 40 MHz and a sampling rate of at least 1 GS/s.

(6) Gas concentration measurement

The meter for measuring the hydrogen concentration shall have an appropriate range and its accuracy shall not be less than ±5% F.S.

7. test methods

7.1 Performance test

7.1.1 Stack consistency test

7.1.1.1 Energy efficiency consistency test

Perform the energy efficiency consistency test as follows:

a) The battery system is charged to 100% SOC;

b) The battery system is discharged at rated power until the discharge cut-off condition;

c) The battery system is charged at rated power until the charge cut-off condition;

d) The battery system is discharged at rated power until the discharge is cut off Condition

e) Repeat steps c) to d) three times;)

f) Record the discharge watt-hour capacity and charge watt-hour capacity of each charge and discharge cycle of each stack;

g) Calculate the energy efficiency of each stack according to formula (1);

Note: For large-scale battery systems, considering the operability of the test, a unit battery system can be used instead of the whole battery system.

$$\eta_{\mathrm{stack},i} = \left(\frac{E_{d1}}{E_{c1}} + \frac{E_{d2}}{E_{c2}} + \frac{E_{d3}}{E_{c3}}\right) \Big/ 3$$

In the formula:

$\eta_{\mathrm{Stack},i}$: Energy efficiency of the i-th stack

E_{dn}: The energy released by the nth charge and discharge cycle of the stack, in watt hours (W•h);

E_{cn}: The energy consumed by the nth charge and discharge cycle of the stack, in watt hours (W•h).

h) Calculate the coefficient of variation of the stack performance according to the following formula:

$$\kappa_{\mathrm{stack}} = \frac{(\eta_{\mathrm{stack,max}} - \eta_{\mathrm{stack,min}})}{\eta_{\mathrm{stack,avg}}} \times 100\%$$

K_{stack} : Range coefficient

$\eta_{\mathrm{Stack,\ max}}$: the maximum energy efficiency in all stacks of the battery system, %;

$\eta_{\mathrm{Stack,\ min}}$: the minimum energy efficiency in all stacks of the battery system, %;

$\eta_{\mathrm{Stack,\ avg}}$: the average energy efficiency of all stacks of the battery system value,%.

7.1.1.2 Electrode difference test

Perform the voltage range test as follows:

a) Charge the battery system to 100% SOC;

b) The battery system discharges at rated power;

c) Measure and record the voltage Udn of each stack at regular intervals until the end of the discharge, test points should be no less than 5. The time interval of each test point should be consistent;

d) The battery system continues to discharge to the discharge cut-off condition;

e) the battery system is charged at the rated power;

f) Measure and record the voltage Ucn of each stack at regular intervals until the end of the charging test points should be no less than 5, and the time interval of each test point should be consistent;

Note 1: It is recommended that the SOC at the end of discharge be 20% and the SOC at the end of charge be 80%.

Note 2: The measurement interval can be determined by the user and the manufacturer.

(g) Calculate the voltage range of the stack charging process and the discharging process according to formula (3) and form a data table.

Note 3: For large-scale battery systems, considering the operability of the test, a unit battery system can be used to replace the whole battery system.

$$\Delta U_{\mathbf{stack},n} = U_{\mathbf{stack},n,\max} - U_{\mathbf{stack},n,\min}$$

Where:

$\triangle U_{Stack,n}$: the voltage difference of the battery system at the nth test point;

$U_{stack,\ n,max}$: the maximum voltage of all the stacks of the battery system at the nth test point, in volts (V);

$U_{stack,\ n,min}$: the minimum voltage of all stacks of the battery system at the nth test point, in volts (V).

7.1.2 Rated power test

Perform the test in accordance with 5.5 of NB/T 42040-2014.

7.1.3 Maximum discharge power test

7.1.3.1 90% SOC maximum discharge power test

Perform the maximum discharge power test of the battery system as follows:

a) The battery system is in the 90% SOC state;

b) The battery system is discharged at a constant maximum power with a discharge time of not less than 10 min;

c) Record the discharge power of step b).

7.1.3.2 50% SOC maximum discharge power test

Perform the maximum discharge power test of the battery system as follows:

a) The battery system is in the 50% SOC state;

b) The battery system is discharged at a constant maximum power with a discharge time of not less than 10 min;

c) Record the discharge power of step b).

7.1.3.3 10% SOC maximum discharge power test

Perform the maximum discharge power test of the battery system as follows:

a) Subject the battery system to a 10% SOC state;

b) Discharge the battery system at a constant maximum power with a discharge time of not less than 10 min;

c) Record the discharge power of step b).

7.1.4 Maximum charging power test

7.1.4.1 90% SOC maximum charging power test

Perform the battery system maximum charging power test as follows:

a) The battery system is in the 90% SOC state;

b) The battery system is charged at a constant maximum power, and the charging time is not less than 10 min;

c) Record the charging power of step b).

7.1.4.2 50% SOC maximum charging power test

Perform the battery system maximum charging power test as follows:

(a) Placing the battery system in a 50% SOC state;

(b) The battery system is charged at a constant maximum power, and the charging time is not less than 10 min;

(c) Record the charging power of step b).

7.1.4.3 10% SOC maximum charging power test

Perform the battery system maximum charging power test as follows:

(a) The battery system is in the 10% SOC state;

(b) The battery system is charged at a constant maximum power with a charging time of not less than 10 min;

(c) Record the charging power of step b).

7.1.5 Rated watt-hour capacity test

Perform the battery system rated watt-hour capacity test as follows:

(a) The battery system is charged to 100% SOC;

(b) The battery system is discharged to 30% SOC at rated power;

(c) Continue to discharge at 30% of rated power until discharge cut-off condition;

(d) Record the SOC of the battery system during discharge;

(e) Repeat a)~d) step 3 times;

(f) Record the discharge capacity and auxiliary energy consumption of the last charge and discharge cycle of the battery system;

(g) Calculate the rated discharge watt-hour capacity of the battery system according to formula (4).

Note 1: For large-scale battery systems, considering the operability of the test, a unit battery system can be used instead of the whole battery system.

$$E_r = E_{sd} - W_{sd}$$

In the formula:

E_r: rated watt-hour capacity of the battery system in watt-hours (W • h);

E_{sd}: watt-hour capacity of the last cycle of the battery system recorded by the measuring instrument, in watt hours (W•h);

W_{sd}: The energy consumed by the auxiliary equipment in the last cycle of the discharge of the battery system, recorded by the measuring instrument, in watt hours (W • h).

Note 2: For the battery system in which the auxiliary energy consumption is supplied by the flow battery itself, the discharge watt-hour capacity recorded by the measuring instrument is the rated watt-hour capacity, that is, $E_r=E_{sd}$.

7.1.6 Maximum watt-hour capacity test

Perform the maximum watt-hour capacity test of the battery system as follows:

(a) Charge the battery system to 100% SOC; b)

(b) Discharge the battery system at a constant power less than the rated value until the discharge cut-off condition;

Note: The recommended discharge power value is 30% of the rated power.

(c) Record the SOC of the battery system during discharge;

(d) Record the watt-hour capacity and auxiliary energy consumption of the battery system;

(e) Calculate the maximum watt-hour capacity of the battery system according to equation (4).

7.1.7 Battery system rated energy efficiency test

Perform the battery system energy efficiency test as follows:

(a) The battery system is charged to 100% SOC;

(b) The battery system is discharged at rated power until the discharge cut-off condition;

(c) The battery system is charged at the rated power until the charge cut-off condition;

(d) The battery system discharges at rated power until the discharge cut-off condition;

(e) Record the SOC of the battery system during charge and discharge process;

(f) Repeat c)~e) step 3 times;

(g) Record the charge and discharge watt-hour capacity and auxiliary energy consumption of the three charge and discharge cycles;

(h) Calculate the energy efficiency of the battery system of the three charge and discharge cycles according to equation (5).

Note 1: For large-scale battery systems, considering the operability of the test, a unit battery system can be used instead of the whole battery system.

$$\eta = \frac{E_{sd} - W_{sd}}{E_{sc} + W_{sc}} \times 100\%$$

equation 5

In the formula:

η :Battery system rated energy efficiency, %;

E_{sd}: The discharge capacity of the battery system recorded by the measuring instrument, in watt hours (W•h);

W_{sd}: Auxiliary energy consumption of the battery system during the discharge process recorded by the measuring instrument, in watt hours (W•h);

E_{sc}: The watt-hour capacity of the battery system recorded by the measuring instrument, in watt-hours (W•h);

W_{sc}: The auxiliary energy consumption of the battery system charging process recorded by the measuring instrument, in watt hours (W•h).

Note 2: For systems where the auxiliary energy consumption is supplied by the all-vanadium redox flow battery itself, the discharge watt-hour capacity recorded by the measuring instrument is the discharge watt-hour capacity of the battery system. That is $\eta=\frac{E_{sd}}{E_{sc}}\times 100\%$.

7.1.8 Capacity retention test

Carry out the battery system capacity retention test as follows:

(a) The battery system is charged to 100% SOC;

(b) The battery system is discharged at rated power until the discharge cut-off condition;

(c) The battery system is charged at rated power until the charge cut-off condition;

(d) The battery system is discharged at rated power until the discharge cut-off conditions;

(e) Record the SOC of the battery system during charging and discharging;

(f) Repeat steps c)~e) for 99 times;

(g) Perform the watt-hour capacity test of the battery system according to the method specified in 8.1.5 and record the relevant data;

(h) Calculate the capacity decay rate of the battery system according to equation (6).

Note: For large-scale battery systems, considering the operability of the test, a unit battery system can be used instead of the whole battery system.

$$R=\left(1-\frac{E_{\mathrm{d}}}{E_{\mathrm{r}}}\right)\times 100\%$$

. equation(6)

Where:

R: Capacity attenuation rate of the battery system, %;

E_d: Battery system net discharge watt-hour capacity in watt-hours (W·h);

E_r: Rated watt-hour capacity of the battery system in watt-hours (W·h);

7.1.9 Low temperature storage performance test

Perform the test according to 5.8 of NB/T 42040-2014.

7.1.10 High temperature storage performance test

Perform the test according to 5.9 of NB/T 42040-2014.

7.1.11 Overload capability test

7.1.11.1 Charging overload capability test

Carry out the battery system charging overload test according to the following steps:

(a) The battery system is discharged to 0% SOC;

(b) The battery system is charged at not less than 1.1 times the rated power, and the charging time is not less than 10 min;

(c) Repeat steps a)~ b) 3 times.

7.1.11.2 Discharge overload capability test

Perform the battery discharge overload test as follows:

(a) The battery system is charged to 100% SOC;

(b) The battery system is discharged at not less than 1.1 times the rated power, and the discharge time is not less than 10 min;

(c) Repeat steps a)~ b) 3 times.

7.1.12 State parameter accuracy test

Perform the state parameter accuracy test as follows:

(a) Install the appropriate voltage, current and temperature measuring instruments in the battery system where voltage, current and temperature sensing devices are installed

(b) Turn on the power of battery management system;

(c) Battery management system collects the signal fed back by the sensing device;

(d) Calculate the deviation between the data collected in step c) and the measured data of the measuring instrument.

7.1.13 SOC accuracy test

7.1.13.1 SOC accuracy test during discharge process

Perform the discharge process SOC accuracy test as follows: :

(a) The battery system is charged to 100% SOC;

(b) The battery system discharges at constant power until the discharge cut-off condition;

(c) The SOC value displayed by the battery management system is recorded every 10% SOC during discharge, ie SOCn, d.;

Note: The recorded SOC interval ranges from is 10% to 90%.

(d) Record the watt-hour capacity En,d released by the battery system from each time the SOC value is displayed to the discharge cut-off condition.

(e) Calculate the actual SOC value and SOC accuracy of the discharge process according to equations (7) and (8)

7.1.13.2 SOC accuracy test during the charging process

7.1.14 Protection function test

Follow the steps below to perform fault diagnosis and processing function tests;

(a) Turn on the battery system to make it in the running state;

(b) Input the fault analog signal such as overcharge, overdischarge, under voltage, over voltage, electrolyte temperature too high, electrolyte temperature too low, electrolyte leakage to the battery system;

(c) Monitor the functional data displayed on the human-machine interface of the battery management system.

7.2 Safety test

7.2.1 Overcharge test

Perform the test according to the provisions of 5.10 of NB/T 42040-2014.

7.2.2 Overdischarge test

Perform the test according to NB/T 42040-20145.11.

7.2.3 Flame retardant performance test

Performed in accordance with 5.14 of NB/T 42040-2014.

7.2.4 Hydrogen leak test

After confirming that the safety measures are guaranteed, perform the battery system hydrogen leak test as follows: a)

(a) Install the hydrogen concentration tester in a fixed test position;

Note: The recommended test position is outside the tank two-thirds of the height, the highest point of the battery system and the small space of the battery system.

(b) Turn on the hydrogen concentration tester and set the detection period to 30 s;

(c) Charge the battery system to 100% SOC.

7.2.5 Insulation resistance test

Performed in accordance with 5.16 of NB/T 42040-2014.

8 test report

A.1 Overview

Based on the tests performed, the test report should provide sufficient correct, clear and objective data for analysis and reference. The report should contain all the data mentioned in Chapter 8. The report has three forms: abstract, detailed and complete. Each type of report should include a corresponding title page and content directory.

A.2 Test report content

A.2.1 Title Page

The title page should include the following information;

Report number (optional);

type of report (digest, detailed or complete);

The author of the report;

The tester;

The date of the report;

The place of the test;

The name of the test;

The date of the test;

The name of the battery system manufacturer;

The test application unit.

A.2.2

Table of Contents

A table of contents should be provided for each type of report.

A.2.3 Test report form

A.2.3.1 Summary report

The summary report should include the following information:

Purpose of the test;

Type of test, instrument and equipment;

Conditions of the test (including electrolyte temperature);

All test results;

Conclusions.

A.2.3.2 Detailed report

In addition to the content of the summary report, the detailed report should include the following data:

A description of the arrangement, layout and operating conditions of the instrument and equipment;

Calibration of equipment;

Explain the test results in the form of graphs or tables;

Discuss and analyze the test results.

A.2.3.3 Complete report

In addition to the content of the detailed report, the full report should have a copy of the original data.

10.3 Appendix 3: Vanadium flow battery - Safety requirements

1 Terms and definitions

The following terms and definitions defined in GB/T 29840-2013 apply to this document. For ease of use, some of the terms and definitions in GB/T 29840-2013 are repeated below. 3.1

Harm: damage or harm to human health, damage to property or the environment.

1.2Risk: A comprehensive measure of the likelihood of injury and the severity of the injury.

1.3Safety: removes the state of unacceptable risks.

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1.4Intended use intended use of a product, process, or service based on information provided by the supplier.

1.5Reasonable foreseeable misuse of reasonable foreseeable misuse The use of products, processes or services not in accordance with the supplier's provisions, but the results are caused by human activities that are easily foreseen.

1.6Leakage leakage The leakage or outflow of electrolyte from the stack, system piping, and electrolyte storage tanks. [GB/T 29840—2013. Definition 2.18]

2 Safety requirements and protective measures

2.1 Overall Security Policy

2.1.1The manufacturer should ensure that:

Determine all foreseeable injuries within the expected life of the battery system; risk assessment of the probability and severity of each of these injuries in accordance with GB/T 21109.3, IEC 61882 or ISO 14121; During the design process , eliminate or reduce the risk of the assessed risk factors as much as possible;

The necessary protective measures (such as providing alarms and safety devices) should be applied to various risks that are not eliminated or cannot be eliminated; the user should been informed of the additional safety measures that need to be taken.

2.1.2 The battery system shall meet the following general safety requirements:

The design and construction of the battery system shall meet the safety requirements under expected use and reasonably foreseeable misuse conditions; the battery system may withstand the misuse of its failure and shall not cause significant damage.

2.2 General requirements

2.2.1 When designing, manufacturing, installing, commissioning, using and maintaining battery systems, the risks associated with the various gases, liquids, dust or vapours released during the above procedures should be avoided.

2.2.2 When designing and manufacturing a battery system, safety factors should be fully considered on the premise of ensuring material performance.

2.2.3 When selecting pumps, valves, piping and other components, the concentration and volume of the electrolyte components and related standards and specifications should be fully considered.

2.2.4 Under normal usage, reasonably foreseeable mis-usage and transportation, the battery system shall have a certain safety structure that is resistant to environmental changes such as falling, vibration, compression, temperature and atmospheric pressure. 4.2.5 During the design process of battery systems, foreseeable hazardous gases should be considered and devices with the function of discharging or treating the above gases should be installed.

2.2.6 During the design process of battery systems, foreseeable dangerous liquid leaks should be considered and devices with the function of collecting, recycling or safely handling the above liquids should be installed.

2.2.7 The battery system should have the necessary monitoring equipment and alarm devices in the proper location.

2.2.8 The design and installation of monitoring and sensing devices shall be reliable and applicable, and the installation location shall meet the maintenance requirements.

2.2.9 The layout, fire protection and civil works of the flow battery compartment shall comply with the requirements of GB51048.

2.3 Electrical safety requirements

2.3.1 The manufacturer shall provide methods to mitigate or prevent short circuits in the battery system, including but not limited to the following methods:

a) Stop the operation of the battery system in the event of a short-circuit fault; b) The complete branch formed by the series connection of the stack shall be equipped with at least one current circuit breaker, fuse or equivalent circuit breaker.

2.3.2 The grounding of the battery system shall comply with the provisions of GB 50169. 4.3.3 For battery systems placed outdoors, a grounding lightning protection system with a strong connection shall be provided and comply with the provisions of GB 50057.

2.4 Gas Safety Requirements

2.4.1 During the operation of the battery system, a small amount of dangerous gas such as hydrogen gas will be produced, a gas discharge or treatment device should be equipped to keep the concentration of dangerous gas in a safe range.

2.4.2 Gas discharge or treatment equipment shall comply with design, manufacture and installation requirements of the manufacturer.

2.4.3 The gas discharge device can be selected from natural ventilation mode or mechanical ventilation mode. The ventilation frequency, ventilation speed and structure of the mechanical ventilation device should comply with the relevant standards.

| Note: For indoor installed battery systems, mechanical ventilation is recommended to keep the hazardous gas concentration within a safe range in the room.

2.4.4 The ventilation device should be kept in working condition during commissioning, operation and maintenance of the battery system.

2.4.5 The end of the exhaust duct of the ventilation system should be placed in a outdoor safe area. It should be marked and away from the fire source and air inlet.

2.4.6 For monitoring and warning of possible hazards, gas concentration sensors and alarm devices can be selectively placed in the appropriate position in the battery system. 4.4.7 Under normal and stable operating conditions, the discharge of hazardous gases shall comply with the provisions of GB 4962.

2.5 Liquid safety requirements

2.5.1 Considering that the battery system may leak certain corrosive electrolyte during installation, commissioning, operation and maintenance, a liquid leakage collecting device should be provided to collect the leakage to avoid the damage caused by electrolyte leakage. The liquid leakage collecting device should have at least one of the following functions: collection, recycling or safe disposal. The liquid leakage collecting device can be used but is not limited to:

Droplet collection tray; anti-overflow baffle; leakage collection flow channel; secondary cofferdam; leakage collection storage tank/pool; neutralization storage tank/pool.

2.5.2 The liquid leakage collecting device shall be made of acid-resistant material or the surface which will be in contact with the electrolyte shall be coated with an acid-resistant layer.

2.5.3 For areas and parts that are foreseeable to come into contact with the leaking electrolyte, an acid-resistant layer shall be applied. The inner wall of the battery system box should be treated with acid corrosion treatment.

2.5.4 It is advisable to configure the sensor for the leaking multiple position, it can provide alarm information when the liquid leakage occurs.

2.5.5 Operators who are exposed to electrolyte during battery system installation and maintenance should be trained. To prevent possible hazards, operators should wear appropriate protective equipment (for example: safety glasses, protective gloves, protective clothing, acid-resistant shoes, etc.).

2.6 Mechanical safety requirements

2.6.1 The main components of the battery system (including but not limited to stacks, electrolyte storage tanks, piping systems, battery management systems) and other auxiliary structures shall be designed and manufactured with full consideration of stability and strength of the structures for the intended operating conditions to make sure there is no risk of tilting, tipping, falling or accidental movement.

2.6.2 When there is a place for the operator to move and stand during the design, manufacture, installation, commissioning, use and maintenance of the battery system, measures shall be taken to prevent the operator from slipping, tripping or falling on the above components.

2.7 Operational safety requirements

2.7.1 Startup

The battery system should be equipped with automatic protection and locking devices to ensure the proper start-up.

2.7.2 Emergency stop function

In order to avoid an uncontrollable danger due to mishandling or other reasons that cannot be corrected by the battery management system itself, the battery system should have an emergency stop that can be both manually and automatically controlled.

2.8 Installation and operation process safety requirements

2.8.1 The installation of the battery system should be in accordance with the manufacturer's requirements.

2.8.2 Various risks caused by the release of various gases, liquids, dust or vapours during installation should be avoided.

2.8.3 Personnel should avoid contact with parts under electrical charge during installation.

2.8.4 The safety signs of hazards or hazards that may exist during the installation process should be provided.

2.8.5 The manufacturer shall provide the necessary safety plan in the product manual. To ensure the safety of personnel and other equipment, operators should refer to the instructions of the product manual when doing debugging, maintenance and cleaning work.

2.8.6 The operator shall use the necessary tools during the maintenance of the battery system. For the operation which involves electrical hazards and electrolyte hazards, appropriate safety tools and protective equipment (such as tools with insulated handles, insulated gloves, and acid proof cloth) shall be provided. Acid suit, etc.) should be equipped.

2.8.7 When the battery system is in operation, the operator should avoid using open flames or equipment that may cause arcing during maintenance.

3 Signs

3.1 The battery system shall have appropriate warning signs, including electrical hazards, flammable gas hazards and corrosive liquid hazards.

3.2 Warning signs should be legible and placed in a suitable location near the source of the hazard.

4 Transportation, storage and disposal

4.1 Transportation

4.1.1 The transport temperature of the battery system should be compliant with the requirements of the manufacturer.

4.1.2 During the transportation of the battery system, it shall not be subjected to severe mechanical collision, exposure to sunlight or rain, and shall not be placed upside down.

4.1.3 During the loading and unloading process, the battery system should be handled softly. It is strictly forbidden to throw, roll or strongly press the battery system.

4.2 Storage

4.2.1 The battery system shall be designed and packaged so that it can be stored safely without damage (for example, sufficient stability and special reinforcement).

4.2.2 The battery system should be stored in a dry, clean and well ventilated warehouse at a temperature between 0 ° C and 40 ° C (or the temperature range specified by the manufacturer).

4.2.3 The battery system shall be exposed from direct sunlight and shall be no less than 2 meters away from the heat source.

4.2.4 The battery system must not be inverted and mechanical shock and heavy pressure should be avoided.

4.3 Disposal

For components and materials (for example, stacks, electrolytes, etc.) of the obsolete battery system, the manufacturer shall provide disposal requirements and methods for components and materials or specifications for reference.