TKI Systeemintegratiestudie

TES1216103

Haalbaarheidsstudie naar de integratie van de Blue Battery t.b.v. elektrische energieopslag voor de gebouwde omgeving: Blue Battery System (BBS)

AquaBattery

COMPASS

Gegevens project

Projectnummer:	TES1216103
Projecttitel:	Haalbaarheidsstudie naar de integratie van de Blue Battery t.b.v. elektrische energieopslag voor de gebouwde omgeving: Blue Battery System (BBS)
Penvoerder:	AquaBattery B.V.
Medeaanvragers:	Compass Infrastructuur Nederland (CIN)
Projectperiode:	1 september 2016 – 1 september 2017
Datum rapport:	November 2017
Contactpersoon:	David Vermaas, technisch directeur AquaBattery

Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken, Nationale regelingen EZ-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.

Samenvatting

In dit rapport wordt een beknopt overzicht gegeven van de resultaten van de TKI Systeemintegratiestudie voor de haalbaarheid van een Blue Battery System (BBS). Een BBS slaat elektrische energie op in water en zout. Via membranen kan het concentratieverschil tussen zoet en zout water worden gebruikt om elektriciteit op te slaan en later op te wekken. Deze studie, uitgevoerd van september 2016 tot september 2017, onderzocht drie aspecten: technische haalbaarheid, economische haalbaarheid en sociale / wettelijke aspecten. Daarnaast beschrijft dit rapport de projectcoördinatie en disseminatie.

Tijdens de studie werd de technische haalbaarheid (hoofdstuk 2) onderzocht via simulaties, hardware-selectie en laboratoriumexperimenten. Simulaties toonden aan dat een BBS met 3 reservoirs tot 20% efficiënter is dan een systeem met 2 reservoirs. Experimenten werden uitgevoerd met behulp van een klein systeem, waarbij stacks met membranen, elektroden, eindplaten, pompen, tanks met zout water, sensoren en een stroombron/load, waarbij opgeslagen en onttrokken vermogen werden gemeten. Gedurende de periode werd het systeem geautomatiseerd met behulp van Matlab in de vorm van een batterijbeheersysteem, waardoor het laad- en ontlaadproces online kon worden gestart via een computer. De efficiëntie van het systeem is afhankelijk van de gebruikte zoutconcentraties in het watersysteem. Tijdens het haalbaarheidsonderzoek werd met name de laadefficiëntie onderzocht, met als resultaat rendementen> 60% die werden gevonden onder niet-optimale omstandigheden (lage temperatuur). Er werd hardware geselecteerd, waaruit bleek dat 3 membraantypes (Fujifilm, FumaTech en Evoqua) worden gekozen om te worden gebruikt in een follow-up proeffabriek, samen met geselecteerde reservoirs en sensoren.

Voor een economische haalbaarheid (hoofdstuk 3) wordt de huidige behoefte aan opslag van elektrische energie geanalyseerd uit gegevens van TenneT. Energieopslagtechnologieën bleken van het grootste belang te zijn voor technologieën voor hernieuwbare energie, zoals zonne- en windenergie, maar er is op moment nog geen doorslaggevende technologie; lithium-ion- en flow-batterijen winnen aan kracht, maar hun specificaties kunnen niet de toekomstige energie-opslag voor duurzame energie leveren. Kosten, afmetingen, levensduur, veiligheid en onderhoud en milieu-impact worden door marktpartijen als belangrijke batterij-eigenschappen beschouwd. We hebben geleerd dat batterijen in 2020 klaar moeten zijn voor "plug-in", met een lange levensduur, met een zeer lage milieubelasting en een prijs van niet meer dan $ 200 / kWh. Slechts één technologie binnen de categorie Li-ionbatterijen zou aan zijn laatste criterium in 2020 kunnen voldoen. Uiteindelijk is het belangrijk voor de BBS om op zijn minst één unique selling point te hebben; in vergelijking met huidige batterijen is dat dat de BBS de meest duurzame batterij is.

Sociale acceptatie brengt nauwelijks hindernissen; de technologie wordt gewaardeerd door een breed publiek. Certificering van batterijen is momenteel voornamelijk gericht op gevaarlijke stoffen, die niet aanwezig zijn in de BBS. Regels om te gehoorzamen en routes om de BBS te certificeren worden beschreven in hoofdstuk 4.

De resultaten zijn verspreid via netwerkevenementen, nieuwsberichten naar aanleiding van het winnen van de Herman Wijffels Innovatieprijs en de Accenture Innovation Award, een museumvideo, wetenschappelijke publicaties, presentaties en als volgende stap een pilot-faciliteit om de technologie in de gebouwde omgeving te demonstreren.

Summary

In this report a concise overview of the results of the TKI Systeemintegratiestudie is provided. A study has been performed to the feasibility of a Blue Battery System (BBS), which stores electrical energy in salt water. Water reservoirs of salt and fresh water are used, and electricity is converted via membranes. This study, performed from September 2016 until September 2017, examined three aspects: technical feasibility, economical feasibility and social/legal aspects. In addition, this report describes the project coordination and dissemination.

During the study, the technical feasibility (chapter 2) was investigated via simulations, hardware selection and laboratory experiments. Simulations showed that a 3-reservoir BBS is up to 20% more efficient than a 2-reservoir system. Experiments were performed using a small system, combining stack with membranes, electrodes, end plates, pumps, tanks with salty water, sensors and a source measure unit for controllable applied and withdrawn power. The system was automated with help of Matlab in the form of a battery management system, enabling to start the charging and discharging process online via a computer. The energy efficiency depends on the utilized concentrations within the system. During the feasibility study especially the charging efficiency was examined, with resulting efficiencies >60% that were found under non-optimal conditions (low temperature). Hardware was selected, which revealed that 3 membrane types (Fujifilm, FumaTech and Evoqua) are being chosen to use in a follow-up pilot plant, together with selected reservoirs and sensors.

For an economical assessment (chapter 3), the current need for electrical energy storage is analyzed from data of TenneT. Energy storage technologies were found to be paramount for renewable energy technologies such as solar and wind power, however no decision is made what technology is most feasible; lithium-ion and flow batteries gain momentum, yet their characteristic do not offer storage with good performance for renewable energy sources. Costs, size, cycle life, safety and maintenance, and environmental impact are deemed as important battery characteristics by market parties. We learnt that batteries should be ready for “plug-in” at 2020, with reasonable size, high cycle life, with very low environmental impact, and with a price not exceeding $ 200/kWh. Only one technology within the Li-ion battery category could meet his latter criterion in 2020. Finally it is important to at least have one very unique selling point, like “the cheapest” or “the most sustainable” battery.

Social acceptance brings hardly any hurdles; the technology is valued by a broader public. Certification of batteries is currently mainly directed to hazardous substances, which are not present in the BBS. Rules to obey, and routes to certify the BBS are described in chapter 4.

The results have been disseminated via network events, with a boost in publicity by winning the Herman Wijffels Innovation prize and the Accenture Innovation Award, a museum video, scientific publications, presentations and as next step a pilot plant facility to demonstrate the technology in urban environment.

Contents

1. Introduction (WP1: project coordination)

This report describes the results of the TKI Systeemintegratiestudie, reference TES1216103, and is carried out by AquaBattery and Compass, between September 1, 2016 and September 1, 2017. A Blue Battery System (BBS) is investigated, which can store electrical energy in an environmental friendly, scalable, safe and cheap way. The BBS uses ion exchange membranes to store electricity in concentration differences of salt in water. Hence, the main components for such battery are water, salt and plastic membranes.

The next chapters discuss the work packages (WP) that have been defined in the proposal of this TKI Systeemintegratiestudie, being:

WP of Fase	***Korte beschrijving***	***Uitvoerders (met namen)***	***Resultaat***	***Geplande begin- en einddatum***
1	Project coördinatie	AquaBattery	Behalen milestones/ rapportages/ afstemming doelen met consortium	Sep 2016 – Sep 2017
2	Hardware batterij & omvormers	AquaBattery, Compass	Technische haalbaarheid	Sep 2016 – Sep 2017
3	Economische haalbaarheid	AquaBattery	Economisch haalbaarheidsanalyse	Sep 2016 – Jan 2017
4	Maatschappelijk onderzoek Juridisch onderzoek	AquaBattery Compass	Maatschappelijk draagvlak Vergunningen, certificering	Feb 2017 – Sep 2017
5	Kennisdeling	AquaBattery, Green Village, TU Delft, Wetsus	Disseminatie van opgedane kennis en resultaten	Feb 2017 – Sep 2017

The remainder of the report is written in English, because of the international pool of employees at AquaBattery.

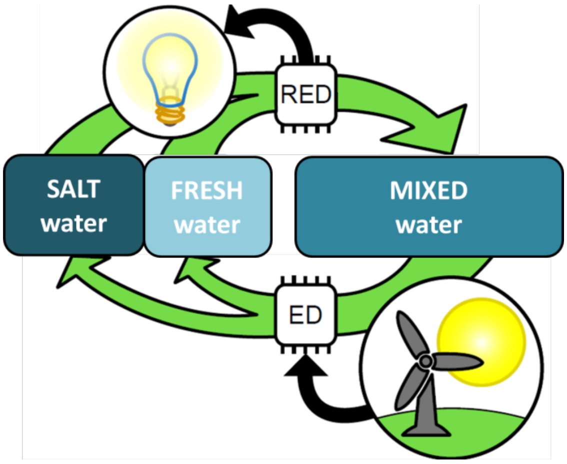
The financial overview is given in Appendix A.

2. WP2: Hardware of Battery (AquaBattery + Compass)

The scope of this section is to present the results of a technology analysis of the Blue Battery as of today, integrating the knowledge from a closed-loop test set-up that was built, and in-depth analysis of a follow-up BBS on larger scale, especially in terms of (hardware) requirements. This analysis was carried out between September 2016 and October 2017, and is made with help of insights gained through experimental work by AquaBattery and Compass, and expertise from other collaborating partners. This section is integrating several points, subdivided in the following points:

- Comparison 2, 3 and 4 reservoir system
- Selection of components for operation of scaled-up BBS system
- Design parameters commercial unit
- Lab-scale validation of osmosis and optimal current density for BBS system
- Automatization of BBS system

2.1 Comparison of 2- and 3- reservoir system



A Blue Battery consists of a membrane stack, where water+salt can be either separated into fresh water and (very) salt water with energy input via electrodialysis (ED), or mixed to generate electricity via reverse electrodialysis (RED).

A Blue Battery can be equipped with 2, 3 or 4 reservoirs. The 2-reservoir system requires least space; the 3- and 4-reservoir systems have partly empty reservoirs, and therefore require more space. However, the 2-reservoir system is also least energy efficient. In case of a 2-reservoir system, the dilute water stream is recirculated over the membrane stack. Because the concentrations changes slowly in the membrane stack, the returning water is a bit more salty every time when it is discharging (or a bit more fresh during charging). This difference in concentration (mixing) increases the entropy and therefore loses energy. We have calculate the loss in energy efficiency of the most compact (2-reservoir) system with respect to the 3-reservoir system. In the 3-reservoir system, the fresh water is captured in a 3rd (first empty) reservoir. When that reservoir is full, the flow will reverse. The advantage is that the fresh-water concentration will remain constant over a period of time, which increases the energy efficiency and voltage stability.

A complete discharge is simulated, which means the power is summed until the concentrations of the fresh and salt water are equal. Subsequently, a complete charge is calculated, i.e., when the concentrations are back to 59 and 1 g/L. This study is performed with Microsoft Excel. The simulated reservoirs are taken as 10 Liter each, with initial concentrations of 1 and 59 g/L, and a flow rate between 60 and 600 mL/min. The current density was 30 A/m^2, and the membrane area 0.21 m^2. Figure 1 shows the concentrations over time for the fresh and salt water streams, for the 2-reservoir system and the 3-reservoir system.

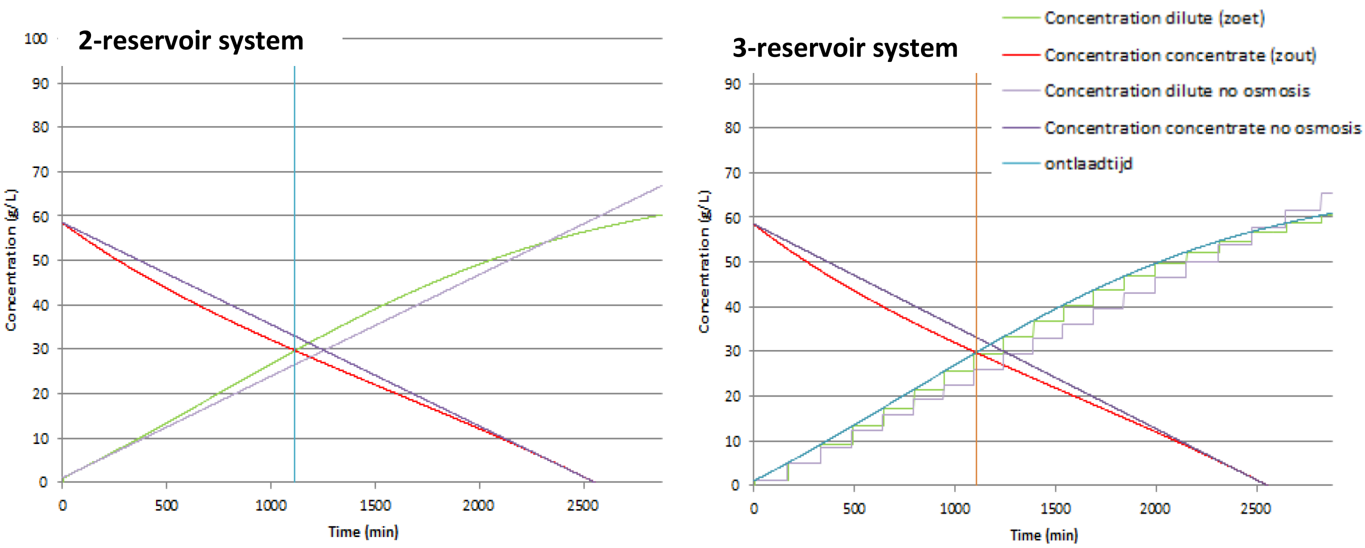


Figure 1: Concentrations over time in 2-reservoir and 3-reservoir Blue Battery system.

The obtained energy can now be calculated from the concentrations and use of the Nernst law. The total obtained energy for the 3-reservoir system is at low flow rates (60 mL/min) approximately 20% higher than for the 2-reservoir system. This difference becomes small when the flow rate increases (2% difference between the systems for 600 mL/min). Because low flow rates are preferred to minimize the pumping power, a 3-reservoir system delivers a significant energy efficiency benefit over a 2-reservoir system.

2.2 Selection of components for operation of scaled-up BBS system

A Blue Battery system is comprised of membrane stacks, reservoirs, pumps, piping, sensors and electronics. We will describe here a selection of these components for a scaled-up BBS system, which is being built at present.

In order to avoid any confusion in delivery of the hardware components for this project, the hardware selection has been divided between AquaBattery and Compass, where the budget of both companies is also taken into account. After this division, Compass provided in-depth desk research in order to select the most suitable products for the follow-up project, where the BlueBattery is constructed. The requirements for these products were formed during several technical meetings with AquaBattery. AquaBattery has selected the membranes, reservoirs and Battery Management System (BMS). Compass supplied the following components for the BlueBattery; Level meter, Conductivity meter, Pressure gauge. The details of these products are listed below.

Membranes

The ion exchange membranes a the key of the system, and also form with the largest share in the costs of the total system. We have considered several commercial membrane types, which are traditionally FumaTech, Selemion and Neosepta membranes. Fujifilm membranes are relatively new in the field, and a batch has been received from them to compare all these 4 membrane types. Fig. 2 show the resistance (which should be as low as possible) and the Open circuit voltage (which should be as high as possible) for a Blue Battery system test.

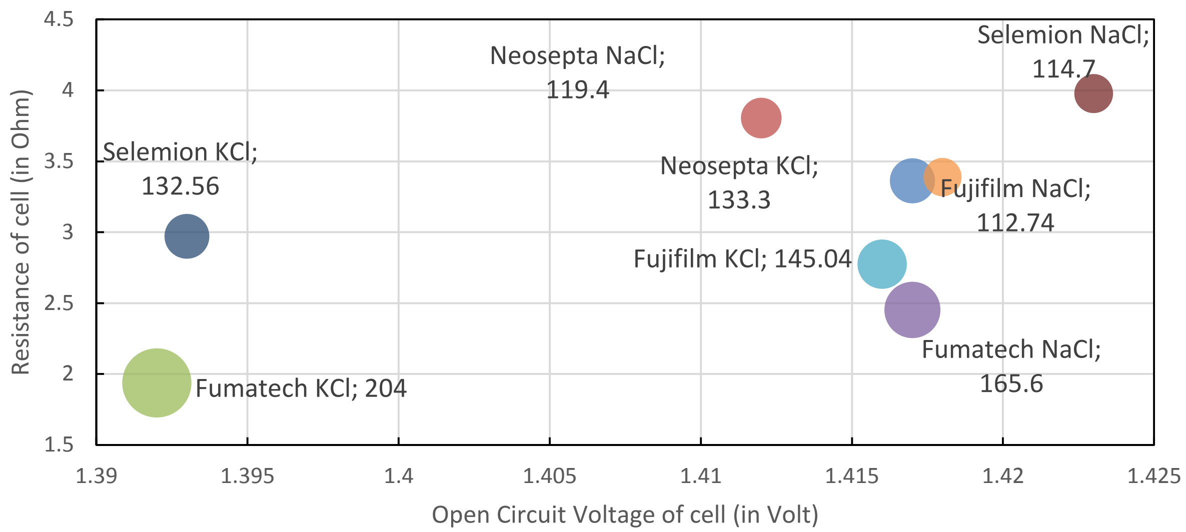


Figure 2: A scatter diagram displaying the OCV and Resistance on the X and Y-axis respectively of all membranes with NaCl and with KCl. The highest net power of the cell combinations is shown by the size of the circle and is written in the labels near the corresponding circle.

Fig. 2 shows that the Fujifilm and Fumatech membranes outperform the Selemion and Neosepta membranes in terms of resistance. Also the type of salt (NaCl or KCl) gives information from this figure; NaCl gives a slightly higher voltage.

Next, we have considered the prices of the Fujifilm and FumaTech membranes. During the project, a third membrane party was introduced, Evoqua. They perform very similar to the FumaTech membranes. The pricing of these membranes starts with approximately 25 euro/m^2, being the Evoaqua membranes, whereas FumaTech and Fujifilm membranes are more expensive. This means, for a 1 kW BBS, having ~2 W/m2, the membranes cost at present at least € 12 500. At present, small-scale experiments (< 100 kW) need extra membranes for testing and sealing the stack.

Membrane casing

Currently, no BBS have been produced at large scale, and no commercial product is available that can contain the membrane piles. So, a membrane casing / membrane stack needs to be home made. The company with most experience in building membrane stacks is REDstack, who built the energy production pilot plant at the Afsluitdijk. For the follow-up project, to actually construct the BBS at 10 kWh scale, we have started collaboration with this party. A cross-flow stack gives the highest performance of the membrane pile.

Reservoirs

Closed-loop systems (i.e., having the water confined in reservoirs) bring the advantage that the water does not have to be purified during operation. Hence, we consider closed reservoirs for the BBS. An easy solution for pilot experiments is to use IBC-tanks, which contain 1 m3 of volume for water. The cost of these tanks is small (approximately 200 euro), and can be easily scaled by using multiple modules.

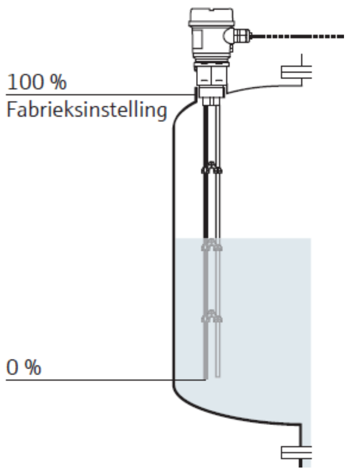
Level meter

Requirements: Floats are duplicate performed in each reservoir (fresh, empty, salt, electrolyte). Floats measure the water height within the applicable reservoir. These should have a resolution of 1 cm or less (volume difference of 1% is enough).

Variations on floats are also possible such as a pressure gauges or ultrasonic sensors. Sensors should have remotely readable output by means of the communication protocol RS485/MODBUS/USB/4-20mA.

Selected product: Niveau meter (Liquicap T FMI21)

This Niveau meter measures accurately the whole volume of the tank using electrode. A low initial capacity is measured at an uncovered sensor. When the tank is filled – and the measuring electrode is



covered – the capacity of the condenser increases. The capacity is transformed into a 4... 20 MA signal.

Specifications:

- Conductive fluids (from 30 µS/cm)
- Bar Length: 150 to 2500 mm
- Process temperature: –40...+100 °C
- Process pressure:–1...+10 bar
- Viscosity: Max. 2000 CSt

Conductivity meters

Requirements: Conductivity meters measure the conductivity within the applicable reservoir.

There should be a total of six conductivity meters. Preferably a range of 0 µS/cm to 200 mS/cm, with an accuracy of 1%. 1% of full range (which is often indicated) is too inaccurate for fresh water, and if this accuracy is specified separately for the sweet compartment, then Compass needs to have a separate meter for sweet portion (with a smaller range). Resolution of 1 mS/cm is sufficient. The temperature should also be measured in order to calibrate the conductivity. Sensors should have remotely readable output by means of the communication protocol RS485/MODBUS/USB/4-20mA.

Selected product: Conductivity meters (C4E)

This digital sensor integrates a transmitter that collects, analyzes and transfers data into a display unit, data logger or PLC. Communication takes place via a RS-485 or SDI-12 protocol. This sensor is made to measure reliably conductivity, and salinity. The C4E sensor uses a 4 electrode technology for accurate data. Conductivity is a broadly deployable measurement, which indices the level of dissolved minerals in the water.

Specifications:

- SDI-12 and RS-485
- 4 Electrode Technology
- 0-200 MS/cm range
- Digital sensor
- Robust
- Waterproof
- Low power consumption

Pressure gauge

Requirements: Pressure gauges are single performed in every water course (sweet, salty, electrolyte). Pressure gauges are installed between dampener and stacks at the fresh and salt water loop, and installed between stacks and tank in the electrolyte watercourse. There should be 3 pressure gauges within a range of 0 to 1.5 bar (1500 mbar). Preferably a resolution of 10 mbar and an accuracy of 20 mbar. Preferably a pressure gauge with a plastic membrane. Sensors should have remotely readable output by means of the communication protocol RS485/MODBUS/USB/4-20mA.

Selected product: LEO Record

The LEO Record is an autonomous battery powered instrument with digital display designed to record pressure and temperature over long periods. The pressure is measured and displayed once per second (shortest interval). The top display indicates the actual pressure, the bottom display shows the record status.

The instruments have the following functions:

ZERO The ZERO-function allows to set any value as a new Zero reference.

UNITS All standard instruments are calibrated in bar. The pressure can be indicated in the following units: bar, mbar/hPa, kPa, MPa, PSI, kp/cm2, (m)H_2O

RECORD The record can be started or ended with the operating keys. The configuration of the record takes place via interface/software.

Specifications

- High measuring accuracy, resolution and robustness
- Display of the actual pressure and the record status
- Recording of the pressure and temperature
- Combination of event-controlled recording and interval recording prevents unnecessary data being recorded (i.e. only measuring the pressure changes...)
- Installation data (and comments) of the measuring station can be stored in the instrument
- Pressure connection with G1/4” thread (other threads on demand)

2.3 Design parameters commercial unit

As concluded in the previous section, a first commercial BBS will comprise a 3-reservoir system, membrane stacks that will produce 1 kW of power, and store 10 kWh of energy. Because the membranes form the largest contribution of the costs and the largest influence on the produced power, we will investigate different membrane types for this upscaled unit. We will investigate the performance of Fujifilm membranes, FumaTech membrane and Evoqua membranes.

An artist impression of the upscaled BBS pilot unit is shown in Fig. 3. The start of this pilot facility has already started; see the photo of Fig. 3 for the water reservoirs. The start of the operation (November 24) is at about the time of writing.

Figure 3: Schematic overview of the upscaled BBS, indicating fresh (blue) empty (white) and salt (green) water reservoirs, and membrane stacks (below in the schematic picture). Right: photo of battery, from September 2017.

2.4 Lab-scale validation of osmosis and optimal current density for BBS system

The goal of this feasibility study, related to the technical perspective, was to build a small-scale fully functional Blue Battery. With help of additional funds and with help of the Delft University of Technology, a set-up was constructed of the following components:

- Stack composed of ion-exchange membranes, electrodes, end plates and mounts for piping;
- Piping system, including pumps to deliver the desired flow velocity within the stack;
- Water tanks;
- Electronic connections, among others comprising a Source Measure Unit as power source and a Data Acquisition Module for sending signals to the pumps;
- Battery management system, a system which will be explained in detail in part 3.

During the experimental phase, stacks have been tested with various numbers of cell pairs, ranging from 5 to 20 cell pairs. Though not defined as a goal, we initially wanted to also test higher number of cell pairs, but due to the limited amount of money we decided to keep this number lower, and instead test different types of membranes from different suppliers (among others of partner FujiFilm).

Furthermore, several volumes were tested, with tank sizes ranging from 1 to 20 litres. Initially we wanted to test as well with volumes up to 80 litres, but due to the limited number of cell pairs it was decided to keep the volumes lower, to save time during the performance of experiments. In Figure 4 a small overview is provided of the Blue Battery as it is running at the moment in Leiderdorp.

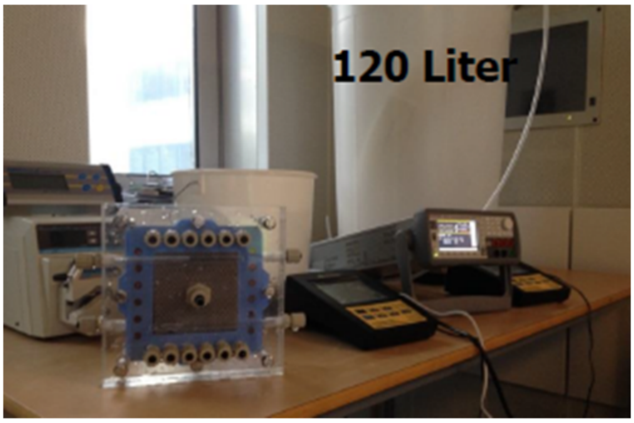


Figure 4: Overview of the Blue Battery system.

To further investigate the technical feasibility of the battery, tests were carried out related to the performance of the battery. The most important characteristics to be determined were:

- Charging and discharge time
- Energy density
- Self-discharge
- Efficiency

We did find out that with higher applied current densities during the charging process, the charging time can be significantly reduced, without highly compromising on efficiency (see Figure 5).

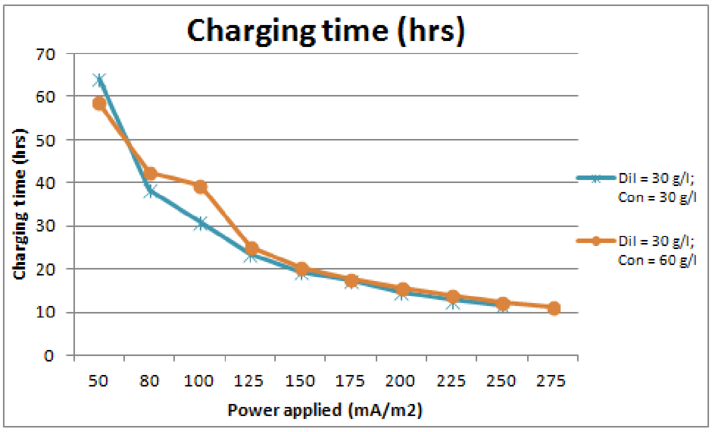


Figure 5: Charging time vs charging current (dil = diluate, con = concentrate)

The energy density, defined as the amount of power that can be stored within a specific volume or weight, was determined as well. The energy density of the battery depends on the utilised concentrations within the tanks, and increases with higher initial concentrations, and increases more or less linearly with charging currents. Visualization of the results are depicted in Figure 6.

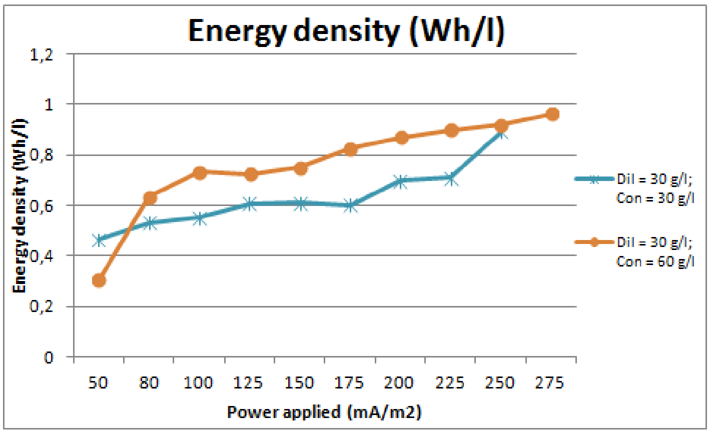


Figure 6: Energy density vs charging current (dil = diluate, con = concentrate)

The aspect of self-discharge was hard to assess as the accuracy of the scales was too low to measure significant changes in volumes of the tanks (due to the water transport through the membranes). Therefore two aspects are considered under self-discharge: a) the water transport from the diluate towards the concentrate, and b) the water losses due to evaporation within the system. These results are visualized in Figure 7 and 8. Water losses due to evaporation integrates an inaccuracy due to reading errors, and due to different observations of the measurements, and therefore this value sometimes shows negative values. In a final battery design this loss cannot exist, due to negligible evaporation of water (closed tanks, only within the stack minor evaporation could take place).

Water transport decreases with higher applied currents. On the other hand it increases with concentrations in the system, this due to the increased effect of osmosis and electro-osmosis at higher concentrations and larger concentration gradients. This is visualized in Figure 8.

Both self-discharge and water transport are also plotted with the temperature in there, and it can be observed that self-discharge increases above a temperature of 20 degrees Celsius, just as water transport increases at higher temperatures.

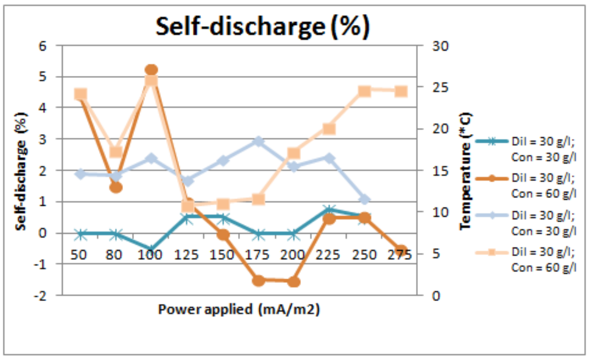


Figure 7: Self-discharge and Temperature vs. charging current.

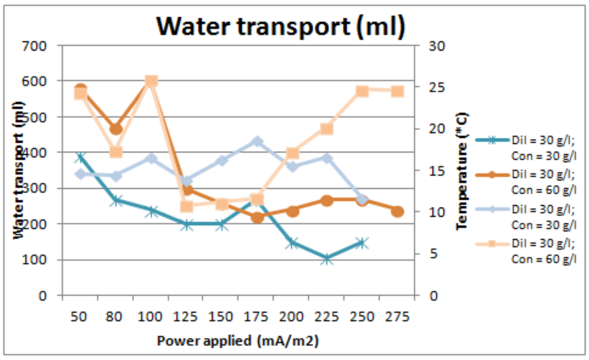


Figure 8: Water transport and Temperature vs. charging current.

The last aspect that was intensively researched was the charging efficiency of the system. In Figure 9 the results are visualized, and one can see that the efficiency shows optima for charging currents in the range of 100-175 mA for the higher concentrations, with a broader range of the efficiency for the lower tested concentrations. The efficiency of the lower concentrations, 30 g/l for diluate and concentrate respectively, shows large drops in efficiency at 125 and 175mA; the exact reason for this remains unknown, but has likely to do with the temperature in the test space. As no heating was applied, the outside temperatures had large influence on the temperature inside, leading to large drops in measured conductivities (as these were automatically correcting for temperature). This effect might have played a role as well for other values. So far a maximum efficiency has been achieved of 60%, but under optimal temperature conditions this could have very well been exceeding 65 or 70%.

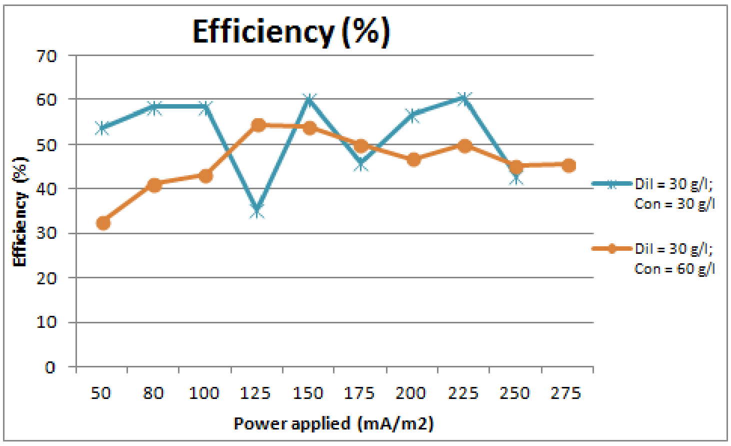


Figure 9: Charging efficiency vs charging current (dil = diluate, con = concentrate)

Furthermore, during the experiments the ED process was continued until very low concentrations (~0.5 g/l). If the process would be stopped at concentrations of approximately 3 g/l power consumption would be significantly reduced, thereby enhancing the charging efficiency, as now power consumption increases exponentially at further desalination. The effect on the power generation efficiency should be subject to further research.

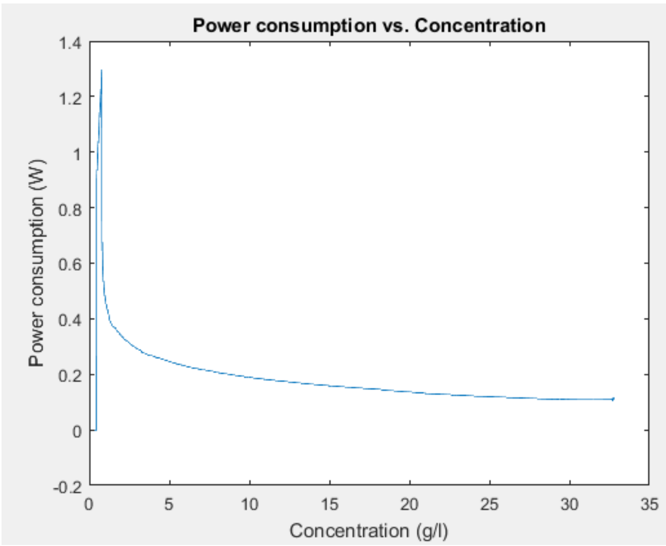


Figure 10: Power consumption vs Concentration of the diluate

That this power consumption increases so significantly is due to the increased resistance within the flow compartments; the resistance to pull one ion through the membrane when the concentration on the other side is already very high, is just very high. This leads to a high voltage at large concentration gradients, visualized in Figure 11.

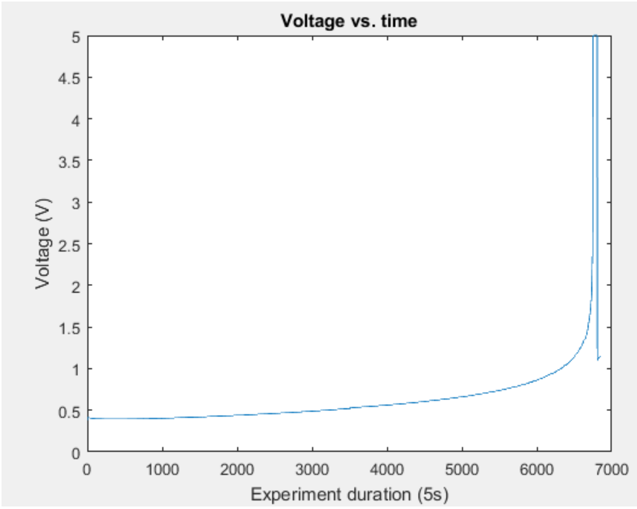


*Figure 11: Voltage vs. Experiment duration. Duration gives the time steps used within the experiment, and are caused by the delay of the measurement devices for example. Multiplication of the total duration (+- 7000 * 5 seconds gives the total duration in hrs).*

2.5 Automatization of BBS system

Automatization of the Blue Battery was a sub goal within the technological part of the development as well, a system that could indicate when to store energy and when to discharge this again. In addition to that, the outline for such a BMS within a functional scaled-up demonstration project was investigated, in cooperation with an expert company in the field of software design and a company with extensive expertise in the field of software and hardware integration.

During a previous project a start was made on this BMS by linking all parts of the system to a laptop. All devices were ordered based on their specifications, but especially to enable reading out and sending data by means of RS-232, a communication protocol that facilitates communication between computers and peripheral devices. Since the pumps demanded various voltage levels as input, a Data Acquisition Module (DAQ-device) was put between the computer and the pumps. All commands for retrieving and sending data are processed with help of MATLAB. At the moment the entire small-scale Blue Battery functions by running a script in this software program, and can be operated via the internet as well. Below a print screen of a section of the code is given for visualization purposes.

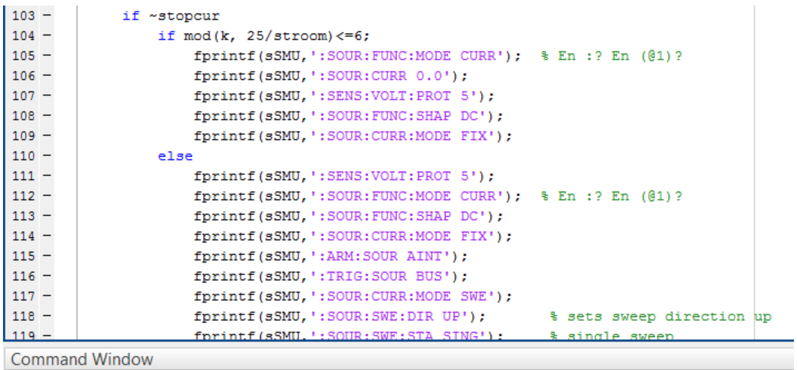


Figure 12: Part of automated programming code of the battery.

With help of this programming code the battery is now able to be ran by a person, but it does not fully operate by itself. In the last year we made a start in automation, and are now collaborating with Technolution and SeaState5 to develop the BMS to the level of autonomy. This infers the integration of different levels of coding into one system, with specific levels for safety, operation and health of the battery. At the moment we are working on a database with all kinds of data related to concentrations, charging and discharging currents, temperature, etc. to enable the full autonomy of the Blue Battery.

3. WP3: Economical viability (AquaBattery)

In this section we elucidate our business analysis of today's electric energy storage market. This study was carried out between September 2016 and June 2017 by means of analyzing publicly available data and having conversations with experts in business and policy.

3.1 Market analysis

At the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding agreement to combat global climate change. This agreement sets out a global action plan, to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C, which needs to be implemented by 2020. For this reason, renewable energy technologies will have a central role worldwide, at least in the coming years.

The transition towards a sustainable energy economy has already started, especially in the residential sector, where most of the newly built houses and small buildings are designed to have ~50% of the energy production from renewable sources (mainly solar panels and heat pumps). As a result of this transformation, batteries are becoming "trendy", as they enable the dwellers to auto-consume very high shares of energy from their solar installations.

Customers from all over the world have expressed their criteria for selecting batteries, which are reported below in accordance to its relative importance.

1. Investment costs: payback time <10 years
2. Size: < 3 cubic metre
3. Capacity and power output: 1.2 - 10 kWh and 1 - 6 kW
4. Safety: no maintenance and very high safety standards
5. Life cycle: at least 5'000 cycles
6. Aesthetics: Tesla's strategy
7. Environmentally friendly: Yes!

In the European market which we are focussing on, the following brands/batteries are currently taking lead: Tesla, Sonnenbatterie, Kostal, Enphase, Fronius, Leclanché, Solarwatt, Varta, Victron Energy, ABB, Siemens and Schneider Electric. The majority of these brands propose two types of batteries to satisfy different customer's needs: lead-acid batteries and lithium-ion batteries, with a stronger and stronger prevalence of the second one due to the high safety standards, low maintenance needs and long(er) life span.

Our interviews to companies and customers operating in this market made us realize that we are on the verge of a real revolution for what concerns the energy usage in households and small buildings, and we strongly believe that by 2025, the majority of all European single houses and villas will have solar panels coupled with batteries.

3.2 Time scale for energy storage

Renewable energy production has a daily pattern (solar) and a seasonal pattern (solar and wind). In addition, periods of high solar influx or high winds have a typical timescale of several days. The consumption has also a daily and seasonal pattern. The question is for what timescale electrical energy storage is required (minutes, hour, day, week, year). To answer this question, historical data of electricity prices are analyzed.

To balance the fluctuations in the electricity production and consumption, the grid manager buys or sells extra electrical power (from storage, or from regulating non-renewable power plants) to balance the production and consumption. The balance is analyzed every 15 minutes. For The Netherlands, the grid manager (for the high-voltage grid) is TenneT. The data on the imbalance quantity (in MW) and pricing (in EUR/MWh) is available from the database of TenneT. Note that this is only a part of the required storage, because balancing is also requested in other geographical levels and time scales.

Data for The Netherlands is use for the period 2010-2016. Fig. 13 gives the relation between the imbalance and pricing for the requested balancing. As expected, the price for feeding extra electricity to the grid is higher when more power is requested, and the price is even negative when power needs to be taken from the grid.

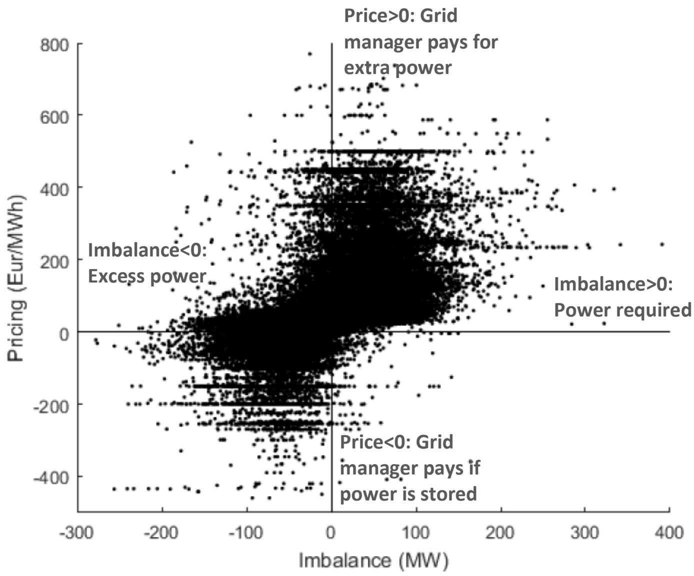


Fig. 13: Pricing versus imbalance for The Netherlands for high-voltage grid.

To analyze the time scale at which the imbalance and electricity prices continue, the autocorrelation of the imbalance and pricing is calculated. The autocorrelation is the correlation between the full series with another part of that same series that is shifted by a time lag. Practically, when a graph has a periodicity, the correlation is high for that specific time lag. Hence, the autocorrelation shows for what time periods an imbalance in the grid occurs. Fig. 14 shows the autocorrelation for a day, week and year.

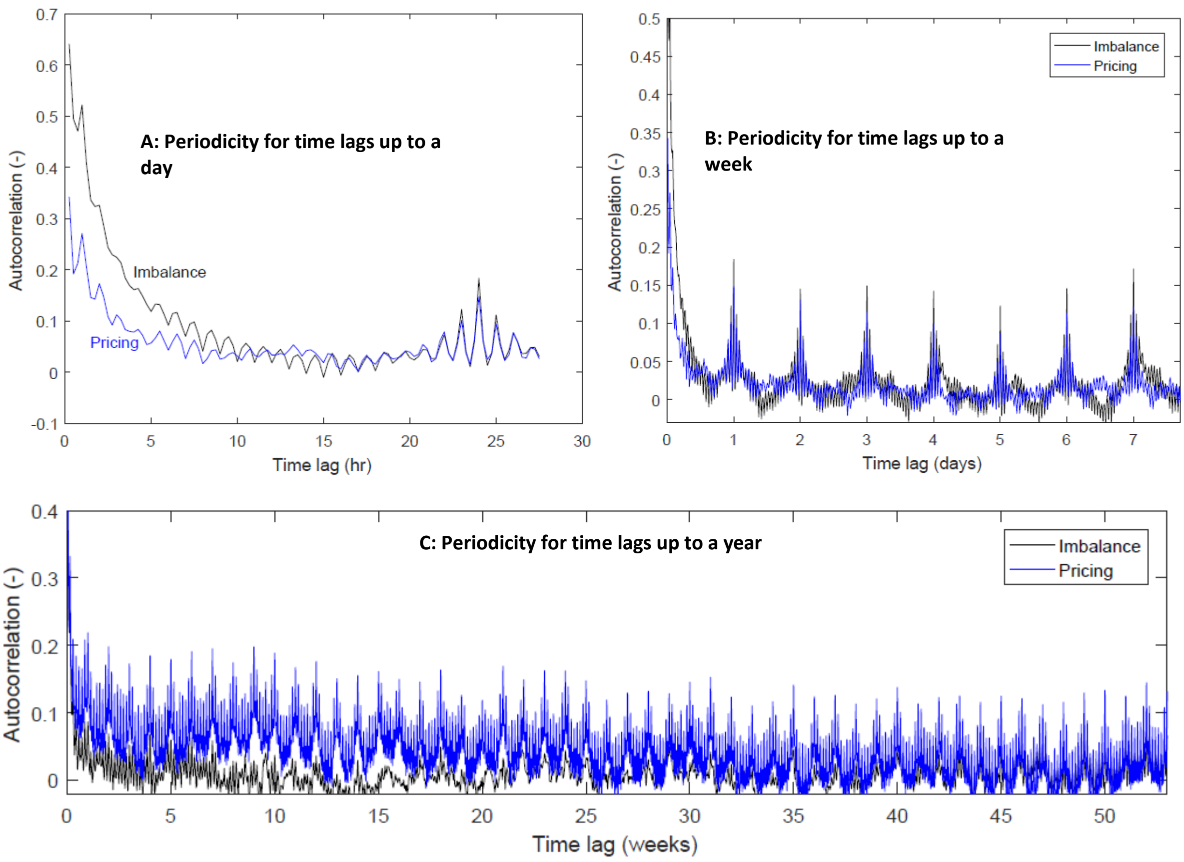


Figure 14: Autocorrelation results of electricity prices (blue lines) and grid imbalance (black) for three time scales

The autocorrelation results show that the imbalance has a typical half-life time of 2 hours (which implies that on average a battery could provide/extract energy for 2 straight hours). Probably power plants have had enough time to regulate their output for longer time scales. Also a peak is visible after 24 hours (Fig. 14A). This is related to the daily fluctuations in consumption and/or production. The daily pattern is also very well visible on the autocorrelation results for a week (Fig. 14B).

When looking to a year (Fig. 14C), there is no strong correlation for the seasons, as the correlation is low for a time lag of 52 weeks (1 year). This implies that there is no strong need yet for seasonal storage. It could be that the data should be further filtered (i.e., de-trended, smoothed) to show the seasonal fluctuations, but it seems that there is no strong need yet for seasonal imbalance in The Netherlands for this period (2010-2016).

The year-graph shows a peak for every week (i.e., 52 peaks over the full graph), which implies that there is a weekly pattern as well. This suggests that the imbalance is still mainly driven by the fluctuating consumption, which has a weekly pattern, rather than imbalances due to fluctuating renewables, which are not related to the day of the week.

Looking to the specifications of the BBS, and looking to the analysis of historical electricity prices, the BBS can fulfill electrical energy storage on 1-24 hours. This will be the primary focus for the short term. When the technical specifications of the BBS improve (higher energy density, smaller system), also the weekly storage can be tackled.

3.3 The batteries for the medium/big scale

For those applications that need electric power in the order of the MW or higher, the market looks extremely different than the residential sector. This market is split into two main parts: electric energy storage to maintain the quality and the stability of the electric output, and electric energy storage to buffer production and consumption. In both cases, the level of reliability of the technology must meet the standards of the national grids, which are very high (guaranteed to work and no failure is allowed). For this reason a lot of pilot projects are undergoing tough tests. During our analysis we have found the DOE GLOBAL ENERGY STORAGE DATABASE made by the Office of Electricity Delivery & Energy Reliability (U.S.A.) where all the electrical storage facilities are listed per country and technology: http://www.energystorageexchange.org/

From the data in this database it is clear that the most developed and spread technology for storing electric energy is hydro-electric power plants. Apart from this, another two key aspects became clear from our analysis. The first one is about the energy regulatory framework. In particularly the EU (but also in most of the world) the regulations are simply not ready to include energy production, consumption and storage onto the electrical grid. In fact, it does not facilitate to let the energy storage market take off. The second one is about the isolated micro-grids of, for example, islands. In this micro environment, it is culturally more acceptable to rely on technologies less stable elsewhere, as people get used to and better understand the reasons behind a power failure. Furthermore, in these places often the regulatory framework is not linked to the one of the mainland, opening the doors to new energy technologies. For these reasons, many companies that are launching innovative energy storage technologies on the market are testing their products in these micro-grids.

3.4 Market acceptation criteria of Blue Battery on medium-large scale

During this market analysis, it became clear that we are approaching a very strict, slow-moving and difficult sector, which is highly influenced by factors like culture, geography, policies, and financial economy. People and organizations in developed countries give for granted the availability of energy in their living or working environments, becoming sometimes reluctant to accept innovative and more sustainable technologies. The challenge we are facing is to successfully bring the Blue Battery (BB) to the market, which is an innovative sustainable energy storage technology we are developing. One thing that is not going to appear in this analysis are the current technical specifications of the BB, because the aim of our research is to market-fit the technical specifications, once we understood the needs of the market. For everything concerning the engineering of the BB we refer to the second part of this document, where we propose the results of the latest experiments and tests ran in the last 12 months.

During our interviews we got to know that companies like energy producers, energy utilities and energy carriers are leaving a transitory moment. In the past 60-70 years they got used to produce, buy and sell energy mainly coming from fossil fuels. However, thanks to the new generations strongly raised with a more sustainable footprint compared to the old one, we are assisting to a shift towards a more sustainable energy mix all over the world. As a consequence these companies need to adapt in every way, from their business models to their physical grids. This shift includes renewable technologies like solar panels, wind turbines and energy storage technologies.

Having said that, we know there is a huge need for energy storage technologies at the medium/big scale, from the order of the 0.1 MW to the GW. As of today, there is not enough energy storage capacity provided to store the energy produced from renewable energy technologies, giving the BB a very good opportunity.

However, we learnt that there is an underlying, almost implicit, feeling between the companies above mentioned. This feeling is that the innovative technologies need to compete with the strongest technology currently available on the market, which is lithium based batteries. This technology has already won the largest market share for small portable applications like portable devices (smartphones, digital cameras, laptops, working tools, etc.), the transport sector (electric and hybrid vehicles), and many others. In the last decade it started also being used for larger storage applications, like the storage of solar energy with a power output larger than the MW. It is important to mention that lithium won his market shares because of its very high energy density, very fast response to store and release energy, and low retail prices. Furthermore, we acknowledge that the final lithium-based batteries costs is almost independent from the cost of the raw material, but is generally dependant on the manufacturing costs and transport, which tells us that an increase in demand will decrease the overall prices. The U.S. Energy Department has set the goal of 125 $/kWh stored in 2022 for lithium-ion batteries. Despite that, we got to know this target will not be met within this time frame. Indeed we estimated that lithium-ion batteries will still store energy for a price of ~200 $/kWh in 2022. Here we propose a graph showing the costs per kWh stored for the different Li-ion technologies in 2014, and an estimation for 2017 and 2020 (Navigant Research, 2014):

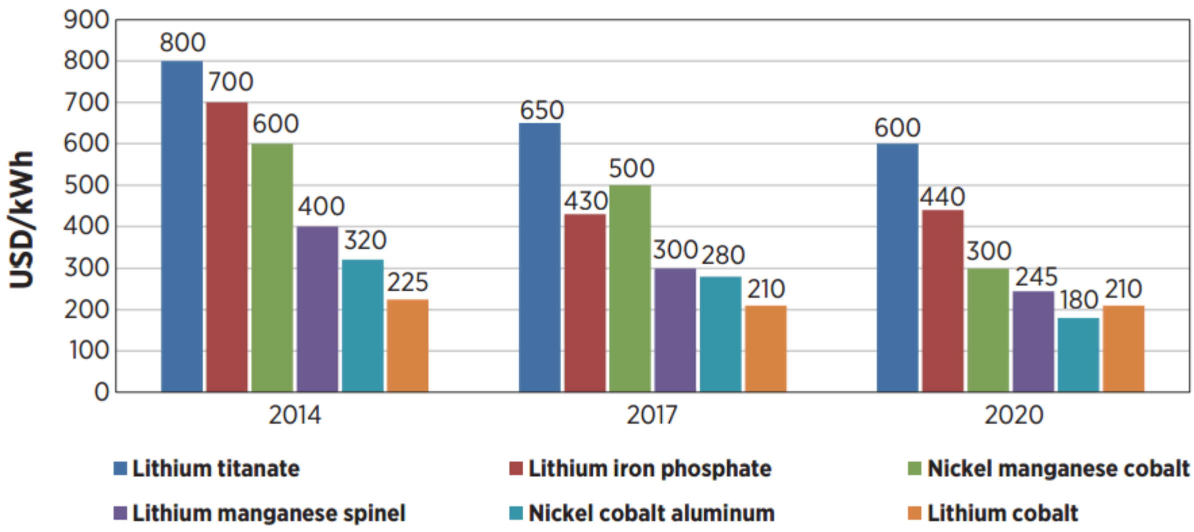


Figure 15: Price developments of Li-based and Ni-based batteries

Certainly lithium-based batteries are not the only ones available on the market. We learnt that also other technologies, specifically flow batteries, are gaining a significant market share. Moreover, this technology could potentially be witnessing a very strong price cut within the next 5 years. Navigant Research produced the following comparison between the competing technologies (Navigant Research, 2014):

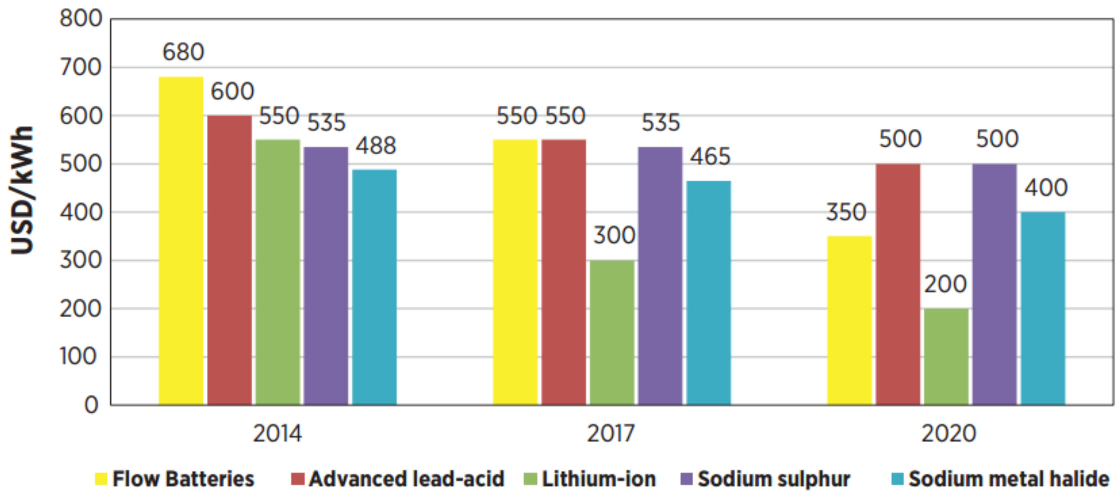


Figure 16: Price developments of battery technologies

Even though lithium-based batteries are proven to have fast response times and higher energy density than flow batteries, the latter technology presents sometimes a more safe and sustainable solution, giving them an extra advantage over the others. This teaches us that the price is a very strong driver, but it is not the only determining one. In any way, price is a very good tool to use in comparing energy storage technologies because it is also very dependent on the performances of the various batteries, beside the manufacturing costs.

One more criterion that we think is important is the size of the energy storage technology. This has nothing to do with the costs, but it is more related to social acceptance. It is common in the energy world to quickly turn our backs even to very clean technologies, like solar panels, only for the so called "NIMBY" factor ("not in my backyard"). It is understandable that a solar panels field can modify the skyline of a beautiful untouched valley, but we need to understand that thanks to that we can maybe decommission far more environmentally disruptive power plants. In any case, we still need to deal with the fact that energy storage technologies that are "too big" will have to go against the public support. This obstacle could be fatal to the certain technologies. During one of our interviews we learnt that the maximum size accepted could be 5 to 10 times bigger than the size occupied by the a lithium-ion battery with the same energy characteristics. Even though this is just a qualitative estimation, it gives us an indication of what people consider a reasonable size.

One example is the CAES (compressed air energy storage), which uses depleted oil and gas fields to pump air in time of excess energy, and extract it in time of energy need. This technology is still under discussion as a lot of people are afraid it could cause serious earthquakes in their regions.

To find a solution to this problem, two options are possible: reduce the size of the energy storage technologies, or mitigate their impact, for instance blending its elements within the nearby environment. This second solution has actually stimulated the interest of all our interviewees, and we believe it can be a winning solution.

We excluded from this analysis hydropower plants and CAES because they are very dependent on geographical locations, and therefore competitive only in specific situations. However, we think it is interesting to report a few numbers, in order to be able to compare them to the other technologies. Hydropower plants are the oldest and cheapest solution for energy storage. The costs varies from a minimum of 0.05 $/kWh to a max of 0.20 $/kWh (Ecofys, 2011). Regarding the CAES, the estimated costs are also in the same range, between 0.05 and 0.15 $/ kWh / cycle.

One more thing we were interested for was to understand if the response time of a storage technology is actually a criterion used for choosing the technology. Definitely there are applications (like voltage regulations or emergency situations) in which the response time is essential, but we also did not find any information regarding the possibility of using one technology that stores a lot of energy but with a slow response time. This suggests us that there could be some applications in which slow response is accepted. However we still need to determine these applications.

The last thing we have learnt is the time-to-market availability. As companies are trying to modify their business models, they are looking for technologies ready to be “plugged in” in 2020 at latest. This is a very important thing to keep in mind when launching an innovative product in this sector, because other technologies are being implemented everyday and could easily replace others. A way to mitigate this is to aim at developing a product with extra unique selling points, like “the cheapest” or “the cleanest” technology on the market.

To conclude we sum up what we learnt. To be successful in this market we need to dispose of a technology that stores energy for less than 200 $/kWh, with a reasonable size, ready within 2020 and respectful towards the environment.

4. WP4: Social & legislation exploration (AquaBattery + Compass)

In this section we elucidate our safety analysis, social response and certification of the Blue Battery System. This study was carried out between February 2017 and September 2017 by means of having conversations with potential customers and experts on technology development and certification.

4.1 Approach safety analysis

Partner Compass has extensive experience in the field of installation, mainly focused on power and electronics, aspects that come together in the field of road engineering for example, but also on low and medium voltage grids. Compass analysed the safety aspects for development and construction of the first Blue Battery demonstration project at The Green Village in Delft, but also for follow-up systems.

At the 24th of August 2017 a dedicated safety event was organized at The Green Village, where several parties who showcase their technology at The Green Village were asked to present cases, and investigate points of attention together with a delegation from the Ministry of Infrastructure and the Environment. The workshop was about identifying potential barriers. In general our Blue Battery system can be considered a highly safe system, with the main safety issue related to potential leakages of reservoirs, what would infer that multiple thousands of litres of salty water end up in the sewage system. It was recommended to draft up a bill of materials to investigate safety in further detail.

4.2 Learning points for demonstration project

The Blue Battery is intrinsically safe, holding no chemicals like quicksilver, cadmium etc. The cells of the battery only contain water, there are no electric currents running through the water or tubing. Therefore the only risk comes from the interface between the battery and the network it feeds or contact within the battery (shed/barn in current design) between 230V installation and water. The cabling of the Blue Battery is currently designed at a safe height, in case of water leakage there will be no contact between the 230V installation and water.

The safety aspects can broadly be subdivided in the three phases of a life cycle: a) beginning with construction, b) the operational phase, c) disassembly of battery.

Construction phase

In the construction phase compliance with building regulations is key. A conventional connection to the electricity grid is needed, and rules similar to solar PV technology apply. This means that both ends of the connectors (male and female) are shielded, which we solved in the pilot plant using MC-4 connectors. Water and electricity flows are separated in the building, and for safety purposes different voltage levels are physically separated by means of different cabinets; distinction is made here between low (<50V), medium (50V – 150V) and high voltage (150-250V). All electricity cables are placed in cable gullies, and are installed at a minimum of 2.00 meters height. The connection of the stacks to the battery management system (BMS) should be performed prior to flowing water into the stacks. In that way, there's no voltage generated in the stacks. All metal parts (sensors, stack housing) are grounded.

Operational phase

During operation it is important to have all documents available on site with respect to used chemicals, indicating quantities, ADR-classes and CAS-numbers. Although sodium chloride is not reactive, when it comes in contact with human eyes it can cause irritation. We recommend to have an eye-shower installed in pilot facilities. Furthermore, a complete list with all components (pumps, sensors, inverters and converters), should be available at all times.

Safety is integrated in the battery management system as well, the autonomously operating controlling system of the Blue Battery. Pumps and currents are automatically switched off in case of emergencies, based on information of the different sensors placed.

Disassembly phase

The Blue Battery System has a large advantage that no toxic materials are used, so no environmental threat is present after disassembling the battery. The major risk is the electricity itself, which means the power should be switched off AND the water should be removed from the stack before disassembling the battery. After the lifetime, the water can be disposed in small batches in the sewage system and the membrane stacks can be re-used or, after the lifetime of 15-20 years, the polymers of the membranes can be recycled into new membranes.

4.3 Regulation / certification

There are safety regulations for batteries, mainly concerning the way they are stored and accessible to people. The NEN-EN1010:2015 norm describes safety regulations for design and construction of low voltage installations. Paragraph 551.8 states the demands for design and construction of installations containing batteries. The installations must be installed in a way that only qualified or sufficient instructed personnel can access the batteries. Either by a locked room or an enveloping packaging. There must be special attention for ventilation, of course this is relevant for batteries containing hazardous chemicals, unlike the Blue Battery.

The NEN-EN 3140 also has interface with batteries, this norm applies to works were alterations in existing low voltage installations are made. Like the NEN-EN1010:2015 norm, it's stated that personnel working at the installation must be qualified and/or sufficiently instructed. The NEN-EN3140 norm says no tools and/or materials which aren't specifically needed for operation or maintenance may be present in the room.

4.4 Which certificates apply?

Norms and Regulations

The Dutch department of housing has written a directive, k&k2008088170, in line with guideline nr. 2006/66/EG from the European Council. These mainly apply to the disposal and handling of hazardous substances.

It is important to take into account that the regulations/directives use definitions for batteries which do not describe the Blue Battery. In that sense, the project doesn't have to meet the demands in these directives. The definition states:

"source of energy obtained by direct conversion from chemical energy to electrical energy, comprising of one/more primary battery cells or one/multiple secondary battery cells".

Because the Blue Battery doesn't use chemicals or chemical reactions as source of energy, these rules do not apply. Furthermore the regulations discuss the maximum amount of quicksilver and cadmium. The regulations (paragraph 2 art.3) oblige the manufacturer to put in place measures to prevent damage to the environment over the life cycle and actively look for further improvements in that context. They also prohibit a maximum amount of chemicals, quicksilver 0,0005% and or 0,002% cadmium. Exceptions are made for tools and "flat batteries" such as watch batteries.

In paragraph 3 it is stated the manufacturer is responsible for intake, processing, recycling and disposal. They are obligated to take back used batteries. Article 6 forces manufacturers to collect at least 25% of their own products, they also have to be recycled.

Paragraph 4 states marking must be at least 3% of the battery surface. If that is not possible due to the size, like watch batteries, the packing must marked instead. The capacity and means of disposal must be mentioned, industrial batteries are excepted.

Lastly paragraph 7 obligates manufacturers to register and report the amount of batteries produced and collected, recycled etc.

General household certifications

There are no other certifications for household appliance then the CE certification, that's because the mark covers all underlying regulations as it is a 'umbrella regulation'. Once a product has the CE-

certification the consumer can trust the fact all regulations are met. The Dutch bureau for securing food and goods safety (*voedsel en waren autoriteit*) listed design demands for electrical products[1]:

- Isolation must be able to withstand the expected load
- Temperature, arc-discharge, or radiation may not reach unacceptable levels
- You have to install safety mechanisms to prevent short circuit or bad functioning elements
- Manufactures are obligated, next to known features for safe use, to state the user limitations.
- The EU low voltage guideline 2014/35/EU must be applied

CE- implications

The CE-certification is required for specified 'product families' traded within the European Union. The certification gives the consumer/user the certainty the product at hand meets all essential requirements related to safety, health, energy efficiency and/or environmental concerns.

The Blue battery is an electrical product and therefore obliged to have a CE-certification. To get a CE-certification the following steps have to be made:

1. Identify the applicable directive(s) ad harmonised standards
2. Verify product specific requirements
3. Identify whether and independent conformity assessment (by a notified body) is necessary
4. Test the product and check its conformity
5. Draw up and keep available the required technical documentation
6. Affix the CE certification and draw up the EU declaration of conformity

Difference in terms of certifications for different markets

There are no big differences between different markets, rules and regulations often don't regard in which market a battery will be deployed.

4.5 Social response

We have spoken to potential customers and innovators about the social response of the Blue Battery. We have analysed these responses at the Herman Wijffels Innovatieprijs event (November 3, 2016), TKI bijeenkomst (March 30, 2017), The Green Village network event (June 6, 2017), and interviews with electricity and grid companies and farmers with solar energy fields.

We have experienced in all events that the (non-technical) public is very enthusiastic about applying the Blue Battery system. The potential customers (electricity companies, farmers) mainly look to the price of the storage and they experience the long lifetime of the BBS as a very strong point. The broader audience values the innovation and the environmentally friendly nature. Safety is no concern for our battery, and is also not the first concern that the public mentions for other batteries; the before mentioned benefits are more appealing.

The social acceptance of the BBS is emphasized by winning both the Herman Wijffels Innovatieprijs (2016) and the Accenture Innovation Award (2017).

[1] https://www.nvwa.nl/onderwerpen/elektrische-apparaten/veiligheidseisen-elektrotechnische-producten

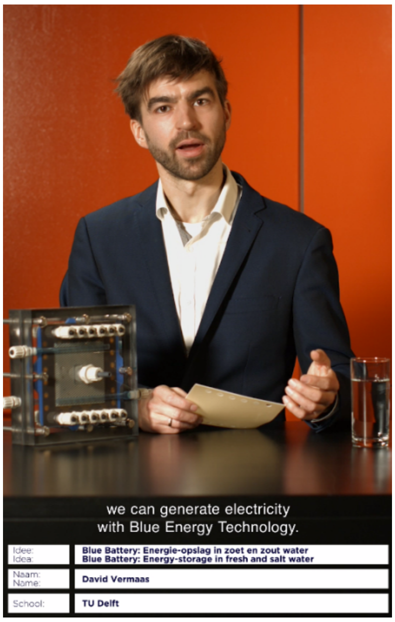
5. WP5: Dissemination (AquaBattery + Compass + TheGreenVillage + TUDelft + Wetsus)

During this Systeemintegratiestudie, the concept of the Blue Battery System has been publicly spread. We give some examples in this section. The dissemination has been done in collaboration with our partners, besides AquaBattery and Compass, mainly The GreenVillage, TUDelft and Wetsus.

Demonstration pilot plant at The Green Village

Our first pilot plant facility, where operation starts at November 24, 2017, is prominently present at The Green Village, at the campus of TU Delft. The construction and operation is funded by grid companies and a follow-up TKI Urban Energy subsidy. The Green Village is a demonstration area of new sustainable technologies, and is often visited by industry leaders, policy makers (among other membranes of the parliament) and local people. A drawing of the concept is printed at the outside of the BBS building, and a window will be installed soon in our pilot to see the operation 24/7.

Maritiem Museum



AquaBattery's technical director, David Vermaas, also working at TU Delft, has recorded an explanation of the Blue Battery technology, which is visible in the Maritiem Museum in Rotterdam. This video is presented in the museum in the section new energy technologies, and is visible for all museum visitors from October 2016 to the end of 2017. Visitors can vote for the different technologies.

Winner of Herman Wijffels Innovatieprijs and Accenture Innovation Award

These events were excellent network events, and the publicity following after winning both awards have broadened the public awareness of our battery system.

Scientific dissemination

One of AquaBattery's employees, Jan Willem van Egmond, also working at Wetsus, has published several scientific papers on the concept of the Blue Battery System (**Van Egmond** *et al,* 2016, *The concentration gradient flow battery as electricity storage system: Technology potential and energy dissipation*, J. of Power Sources and **Van Egmond** *et al.,* 2017*, Energy efficiency of a concentration gradient flow battery at elevated temperatures*, J. of Power Sources). He has also presented the work at a 2-day seminar at Wetsus, visited by many water technology scientists and industries.

6. Outlook

After obtaining the TKI Systeemintegratiestudie, we (AquaBattery and Compass) have obtained funding from electricity grid companies (Enexis, Alliander), as co-funding with subsidies (TKI Urban Energy) to actually build the upscaled Blue Battery system. This pilot facility will be opened for the public at November 24 of this year (2017), and modularly scaled to 10 kWh.

In addition, another project has been established by AquaBattery to build water batteries with acid-base for European islands. This project is funded by the European Union (Horizon 2020), and collaboration with research institutes and international energy companies.

Both developments will help us to develop a modular Blue Battery for stationary electrical energy storage. Apart from the above mentioned pilot facilities, we plan to sell a series of standardized Blue Battery products in mid 2018. We’re grateful for the opportunity to investigate the opportunities of the BBS in this TKI Systeemintegratiestudie.

Appendix: Financial overview

The financial overview is provided in 3 tables: a general overview of the costs, a table with man hours, and a table with material costs. These tables are shown below.

The spent costs are close to the project budget. The man hours are according to the budget for AquaBattery and more than requested for Compass. The materials costs are slightly higher than budgeted for AquaBattery, and slightly lower for Compass. In total, both parties have a project cost that is a bit higher than requested. The excess has been paid from own resources.

General overview

Afrekening TKI Systeemintegratiestudie TES1216103

Bestede uren	**Uren**	**Kosten**	**Begroot**
AquaBattery	758	€45,480	€45,480
Compass	136	€8,160	€7,500
Totaal uren	894	€53,640	€52,980

Materiaal-, apparatuur- en derden	**Kosten**	**Begroot**
AquaBattery	**€14,333**	€13,910
Compass	**€4,034**	€4,536
Totaal materiaal	**€18,367**	€18,446

Totaal per partner	**Kosten**	**Begroot**
AquaBattery	**€59,813**	€59,390
Compass	€12,194	€12,036
Totaal	**€72,007**	**€71,426**

Man hours

Afrekening TKI Systeemintegratiestudie TES1216103

AquaBattery

<u>Bestede uren</u>

Werknemer	WP	Uren	Tarief	Kosten
David Vermaas	1	32	€60	€1,920
David Vermaas	2	40	€60	€2,400
David Vermaas	5	16	€60	€960
Emil Goosen	1	56	€60	€3,360
Emil Goosen	2	72	€60	€4,320
Emil Goosen	3	120	€60	€7,200
Emil Goosen	4	48	€60	€2,880
Emil Goosen	5	32	€60	€1,920
Maurits Maks	2	216	€60	€12,960
Maurits Maks	4	62	€60	€3,720
Maurits Maks	5	64	€60	€3,840
Subtotaal		**758**		**€45,480**

Compass

<u>Bestede uren</u>

Werknemer	WP	Uren	Tarief	Kosten
Ruben van Ardenne	5	16	€60	€960
Leen Kok	2	24	€60	€1,920
Leen Kok	4	16	€60	€1,440
Michael Ooms	2	24	€60	€1,680
Michael Ooms	4	24	€60	€1,920
Marike Doedens	5	32	€60	€1,920
Subtotaal		**136**		**€8,160**

Material costs

AquaBattery

Materiaal	Omschrijving	Kosten (ex. BTW)	BTW	Kosten (incl. BTW)
Materiaal van batterij (membranen+elektroden)				
Fujifilm Europe BV	Membranes type 10, invoice QXF25001335	€ 4,085.00	€ 857.85	€ 4,942.85
Blokker	Membraanbakjes	€ 28.11	€ 5.61	€ 33.72
Blokker	Membraanbakjes	€ 63.66	€ 11.05	€ 74.71
Magneto Electrodes	Elektroden voor membraanstack	€ 1,321.12	€ 277.44	€ 1,598.56
Wildkamp Flow balancers	Waterleidingen	€ 30.76	€ 6.46	€ 37.22
Toolstation	Gereedschap voor stack bouwen	€ 529.60	€ 111.21	€ 640.81
Bleijenberg stansvormen	Stans voor membranen	€ 288.00	60.48	348.48
Oil Control Systems Drip tray	Lekbak	€ 49.50	€ 10.40	€ 59.90
Zeefdrukland	Spacers	€ 44.88	€ 8.53	€ 53.41
Zeefdrukland GbR	Spacers	€ 76.48	€ 16.06	€ 92.54
EM-Technik Connectors	Connectors voor waterleidingen	€ 693.52	€ 145.64	€ 839.16
AliExpress	Carbon plates	€ 25.01	€ 5.25	€ 30.26
Titaniumshop	Titanium parts	€ 121.00	€ 25.41	€ 146.41
Toolstation	Boorsets	€ 16.97	€ 3.56	€ 20.53
Subtotaal		**€ 7,373.61**	**€ 1,544.94**	**€ 8,918.55**
Pomp voor batterij				
Metrohm Nederland	062-505406, pompkop	€ 546.30	€ 114.72	€ 661.02
Metrohm Nederland	Pompkop	€ 495.00	€ 103.95	€ 598.95
Hornbach	Demiwater	€ 27.56	€ 5.79	€ 33.35
ebay, import- en verzendkosten	Pomp Masterflex	€ 326.25		€ 326.25
ebay, van Saja Surplus	Pomp Masterflex	€ 462.00		€ 462.00
Subtotaal		**€ 1,857.11**	**€ 224.46**	**€ 2,081.57**
Sensoren voor batterij				
Ultrasonic Flow Management	Stromingsmeter	€ 2,100.00	€ 441.00	€ 2,541.00
Milwaukee	Geleidbaarheidsmeter	€ 639.67	€ 134.33	€ 774.00
Frontline Safety	Gasdetector	€ 269.63	€ 56.62	€ 326.25
AliExpress	Flow meter	€ 45.17	€ 9.49	€ 54.66
Subtotaal		**€ 3,054.47**	**€ 641.44**	**€ 3,695.91**
Electronica voor testen batterij				
Eleshop	Voeding batterij	€ 219.79	€ 46.16	€ 265.95
Conrad	Electronic parts	€ 301.41	€ 63.30	€ 364.71
Conrad Electronic Benelux	Electronic parts	€ 129.11	€ 27.11	€ 156.22
Conrad Electronic Benelux	Electronic parts	€ 78.17	€ 16.42	€ 94.59

National Instruments Ni-DAQ	Analoog-digitaal convertor	€ 233.29	€ 48.99	€ 282.28
Megekko	Aansturing batterij	€ 866.94	€ 182.06	€ 1,049.00
CoolBue B.V.	Data storage	€ 218.98	€ 45.99	€ 264.97
Subtotaal		**€ 2,047.70**	**€ 430.02**	**€ 2,477.72**

Totaal AquaBattery		**€14,332.88**	€2,840.87	€17,173.75

Compass

Materiaal	**Omschrijving**	**Kosten (ex. BTW)**	BTW	Kosten (incl. BTW)
<u>Sensoren</u>				
E-direct	Niveau meter	€ 1817.00	€ 381.57	€ 2198.57
E-direct	Inkortset	€ 12.14	€ 2.55	€ 14.69
Keller instruments	Drukmeter	€ 2104.50	€ 441.95	€ 2546.45
Keller instruments	Stekker + kabel 10 meter	€ 100.05	€ 21.01	€ 121.06
Subtotaal		**€ 4,033.69**	**€ 847.07**	**€ 4,880.77**

Totaal Compass		**€4,033.69**	**€ 847.07**	**€ 4,880.77**
TOTAAL		**€18,366.57**	**€3,687.95**	**€22,054.51**