An open hardware platform for a zinc air fuel cell

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Abstract

One of the most important challenges for renewable energies are the lack of large-scale saisonal energy storage systems for beeing able to take the during summertime abundant solar energy to the wintertime. Even for performing some research on this subject sufficient test cells can be prohibitively expensive and unreliable. The ZACplus system is an experimental platform for doing research on a zinc air fuel cell with a low threshold. Its components are designed to be comperable inexpensive because many of them can be self-produced, e.g. by utilizing a 3d-printer. The needed construction plans and all ressources are available under Open Source Hardware (OSHW) licenses and free to become spreaded and extended. Therefore they are also well suited and approved for even citizen-science projects.

Introduction

Today's lithium based solar storage systems have a great degree of effiency and are well suited for saving small amounts of energy for a short time. They may be useful to take small amounts of harvested solar energy from the day into the night or maybe even be capable to bridge a few cloudy days, but even this only in a magnitude of order of a few KWh capacity. They are not well suited for taking large amounts, like e.g. 6000 KWh from summer into winter. Technically they would be able to do that, but there are two problems, the first is that the price for that would simply not being realistic in an economical sense. Meaning, if you would have to pay a few million dollars for such a storage system then its way cheaper to pay the energy bill for the rest of your lifetime. The second is the amount of space needed for them, which is in the magnitude of order that you wpould need an extra large hall for it. So, for the most people this kind of storage is not feasible. But thats the kind of technologie which is commercially available on the market.

Other large-scale technologies, like hydrogen or hydrocarbon-synthesis may exist or are under strong development, but they are not yet regularly and commercially available in the sense of end-user applications. So its not surprising that new research projects based on an Open Source Hardware approch occur on the surface, like Peter B. Allens All Iron Battery 3.0 [1] or the open-source platform for 3d printed RFB test cells by Connor et.al [2] or the RFB Dev Kit by the FBRC [3].

The researched and utilized systems can be quite different like flow batteries or other technologies, with all their pro's and con's.

The ZACplus system is of the kind "alkaline metal air fuel cell" and to our knowledge so far the only OSHW project in this field. Here the approach is to use the zinc metal as an energy carrier in combination with a fuel cell. A fuel cell is a galvanic tertiary cell which per definition delivers electric energy as long as it is feeded with the fuel (which is located externally and outside of cell). Zinc is (unlike lithium) an abundant material whith a higher occurence than even lead, what means, its cheap and widely available.

Zinc air batteries have a high energy-density with a (theoretical) maximum value of 1370 Wh/Kg which is about 4 times higher as lithium batteries and about 30 times as much as lead acid batteries. Whereas this doesn't matter so much since we want to use it in a stationary application, but it is nevertheless a nice to have feature.

There are several companies and projects trying to build it as a secondary cell (like a rechargeable battery) where every part of the system takes place within one close box. Our approach differs in that respect that the recharging of the burned fuel (the zink oxide, ZnO) can happen in another place and at another time (e.g. in the summertime). We call the extra device for that "recycler" in opposite to the "fuel cell" where the discharging happens. So, concerning the storage, we have to deal with two materials, which is the zinc, which we have to store for the use in the wintertime and oth the zink oxide, which we have to store for becoming regenerated back to zinc in the summertime. Since zinc is a metal with high weight compared to the volume, we dont need so much volume to store that. Even a few tons of zinc which might be sufficient for e.g. 6000 KWh would need only the volume of a cube with 1.5 m edges-length. So far the theory, in practice it may

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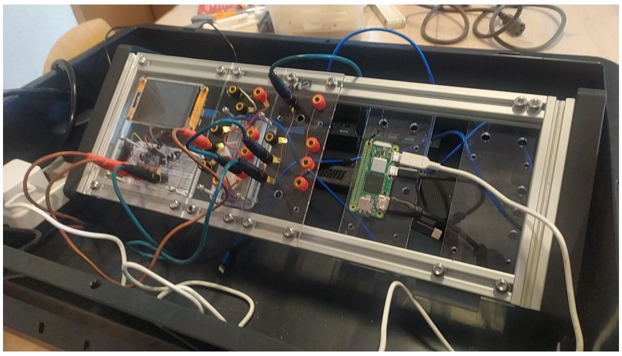

Figure 1: *The sample rig, including CYD, load-module, Patchbay and a Raspberry Pi Zero 2 w*

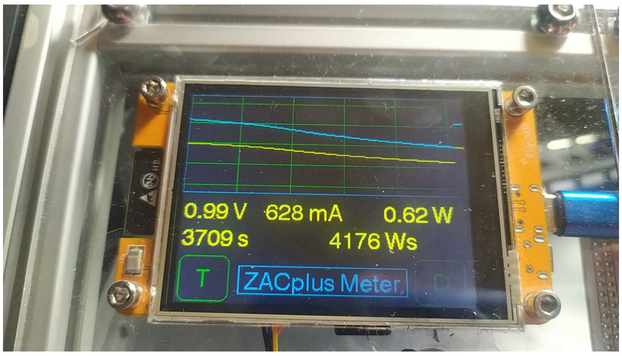

Figure 2: *CYD Display for shortterm monitoring*

be a bit more because maybe we want to store it as a slurry, together with some electrolyte, but its obvious that storage need not much volume. And it is absolutely save, compared to the storage of fuels like hydrogen or hydro-carbons.

Here we want to give an overview of the system as an open research-platform for experimental purposes, wich consists of the above mentioned recycler, which we already have introduced in [4] and the fuel cell itself, see [5].

Meanwhile we have developed for the fuel cell a special sample rig, which allows longterm measurements for even weeks or months, which is in this field an important and useful thing. (see figure 1, 2, 3).

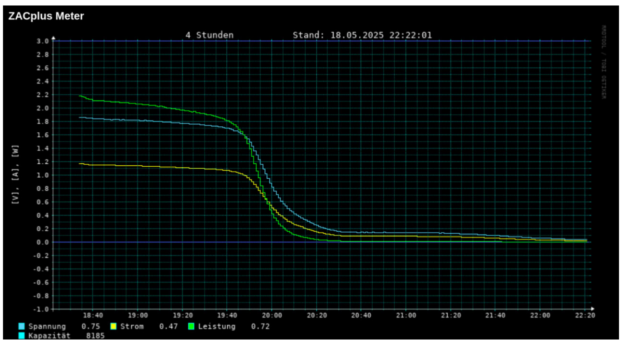

Figure 3: *Longterm monitoring visualization*

Figure 4: *A sponge of regenrated zinc is accumulated*

Methods

The components of the recycler

The recycler is build as a framework of 20x20 tslot profiles, wich embrace a beaker glas as containment for the electrodes and the ZnO-enriched electrolyte. And it provides a kind of gallow, on which a spring scale is mounted which is connected to one of the electrodes. The electrodes are fine wire mesh from steel-wire and are both located within the beaker glas and forming all together a galvanic cell.

The electrodes are connected by a cable with crocodile clips to the plus and minus pole of lab-powersupply.

When a DC-current is applied to the system, the ZnO releases the oxygen and therefor became transformed into pure zinc, which accumulates at the electrode which is connected to the spring scale and so we can measure the amount of regenerated zinc relativ to the applied amount of energy. (see figure 4)

However, releasing the oxygene is a splashy process, which sprinkels micro-drips of the potassium-hydroxide electrolyte all over the tslot-frame. Therefore we developed a 3d-printable lid with smnall openings for the cable, to avoid that. We further designed a 3d-printable ground-plate with a special profile, that helps ensuring that most of the precipitated ZnO (when higher concentrated) is spread more evenly and on the top of the steel mesh of the other electrode, for ensuring that it becomes part of the galvanic reaction. (see figure 5)

The components of the cell

The whole apparatus ist placed within a plastic box (for safety reasons, just in case of leaks) and there are some 3d-printed structural elements, which divide the space and act as a base to incorporate other functional parts, e.g. two big parts which form a mold for the big 9 L tank, also we have a base for the

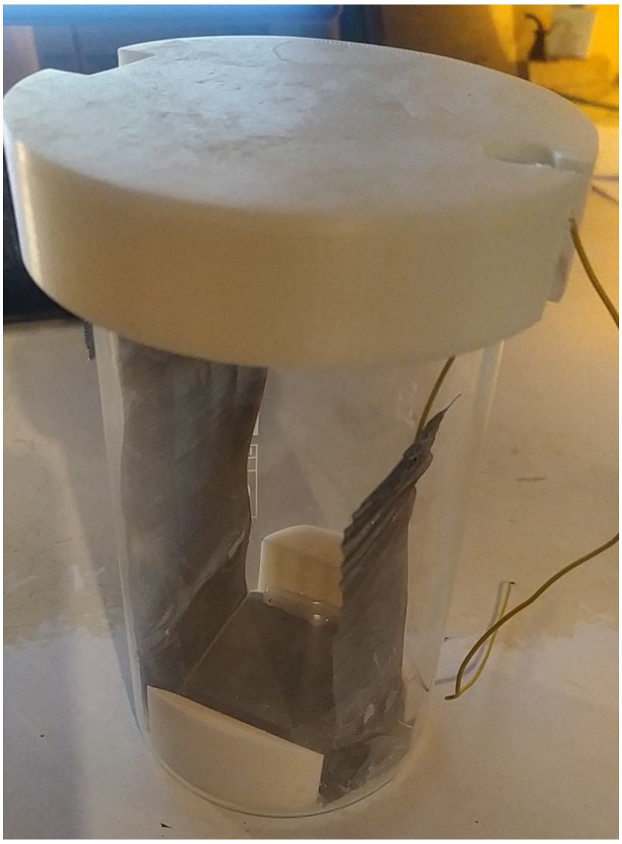

Figure 5

Figure 6: *Survey of the containing box with structural elements, mostly 3d-printed*

pump-station and a holder for the reaction-chamber. The other parts are mostly for distancing purposes. (see figure 6)

The reaction-chamber has integrated holes for the big zinc anode and the cathode holder, and additionally some connectors for tubing and conducts for the power cables.

Chemical compatibility testing

Since the potassium hydroxide is a very strong alkaline electrolyte we had to test the chemical compatibility with several kinds of 3d-printer filaments, as well with several substances we wanted to use for glueing or thogtening purposes, like silicone.

The kinds of filament that we tested were ASA, ABS, PLA and TPU. From former experiences we knowed already that PETG is not well suited so there was no need to test this too. We throwed an about 10cm long piece of each filament into a containment and filled it up with electrolyte. Then we waitet a longer time for any signs of degradation. The result was clear and simple: PLA startet dissolving at the same day and was completely dissolved the next day (see figure 7). All other filaments stayed ok. We left them for about 10 weeks in the electrolyte and there were no signs of any kind of degradation visible, also the filaments stayed firm and showed their usual

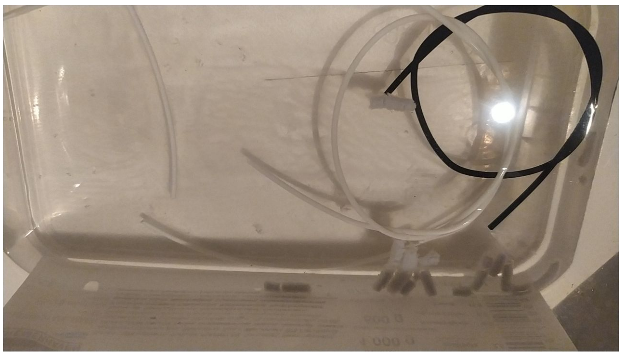

Figure 7: *Testing ASA (white), ABS (ivory), PLA (grey) and TPU (black). The PLA was desolved the next day*

Figure 8: *Four different kinds of glue: Silicone. Acrifix, M2 and E6000*

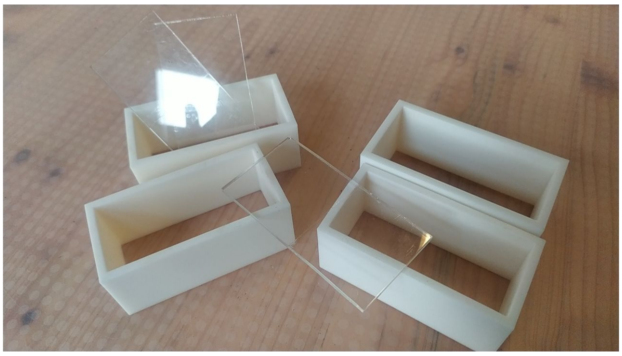

Figure 9: *Test-boxes with acrylic plates that should be glued on it for testing the tightness*

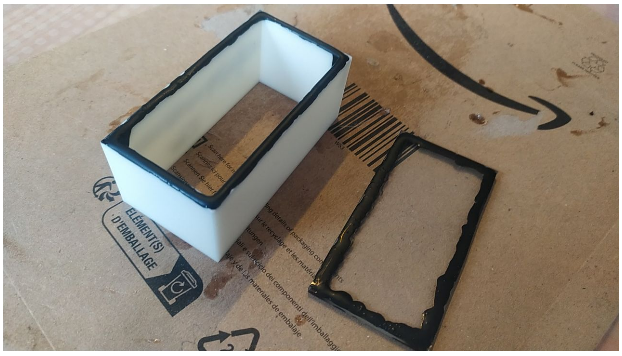

Figure 10: *Glueing one box with the black M2 EPDM glue*

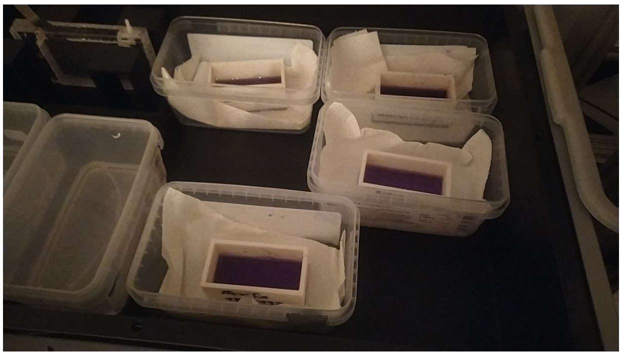

Figure 11: *The boxes were placed into a bigger containment (with a lid) and then left for 10 weeks*

bending-behaviour, so we ended that experiment and used the ASA and ABS for printing our parts.

For the glue-tests, we choosed 4 kinds of glue, that was Silicone, Acrifix (a special glue for acrylic), M2-EPDM-glue (which we used often in former prototypes) and E6000 (see figure 8).

As test-setup we had printed 4 boxes from ABS wihout a floor. As floor we glued an acrylic plate under the box, using one of the test-candidates. The box was then filled with electrolyte that we had also dyed blue with ink and then placed into a bigger container, with a paper towel underneath. The idea was, that if any leakage occur, the blue electrolyte would be running out and then soaked by the paper towel which would be well visible. (see figure 9, 10, 11).

After 5 or 6 days the box with the M2-EPDM became leaky. After about 2 Weeks the box with the silicone became also leaky. The other two boxes stayed tight for about 10 weeks and then we finished the experiment.

Electrolyte preparation

For preparing on amount of 500 mL of 6 molar potassium hydoxide (KOH) we need the molar mass of the KOH, which is 56,11 g/mol.

This results in 6 mol/L * 56,11 g/mol *0,5 L = 168,33 g KOH (which have to be resolved in 0,5 L of Water).

With the new prototype we need larger amounts of several liters, so to adopt to this for 1 L we need 336,66 g KOH (which have to be resolved in 1 L of water).

The reaction between the KOH and the water is usually quite strong, therefore one must follow this rule: Never throw the water onto the KOH ! Always put at first the water into a containment and then add the amount of KOH in small portions and wait in between until the upcoming temperatur gets lower again.

3D-printing procedure

For the design and construction of the 3d-printed parts we use the open source CAD-programm FreeCAD. (see figure 12)

For slicing and control of the printing we used Bambu-Studio, which is also open source and the prints were made ona Bambulab P1S 3d-printer. Because this on is able for high-speed printig we also made use of the original Bambulab filament, which is well suited for speed.

But each other 3d-printer and filament should wor as well, so one can use what is available.

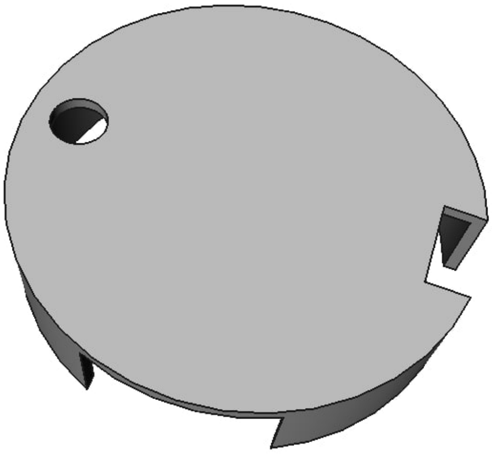

Figure 12: *The lid for the recycler was constructed with FreeCAD, an open source CAD-software*

Figure 13: *Producing a thicker zinc anode by casting*

Non-3d-printed components

There are several non-3d-printed parts, eg. the all the electrical parts for the sample rig, several cables with banana-jacks and -plugs. For the cell we need lots of silicone-tubes and appropriate connectors. All theses smaller parts are listed in the BOM and widely available, so we dont want to get into detail here. But there are some bigger parts, which should be mentioned:

- Meanwhile we use a thicker zinc-anode which we produce by casting. This is simply for convenience, one can use as well thinner zinc plates, e.g. from roof gutters, they work as well, but in longer experimental runs one more often has to exchange them because they are faster consumed than thicker ones.

- Some parts are mady from acrylic plates with 3mm thickness, which are used for the window in the new exchangeable gas cathode holder and others for the top plates of the sample rig. Usually we cut them with a cheap K40 lasercutter and use the open source

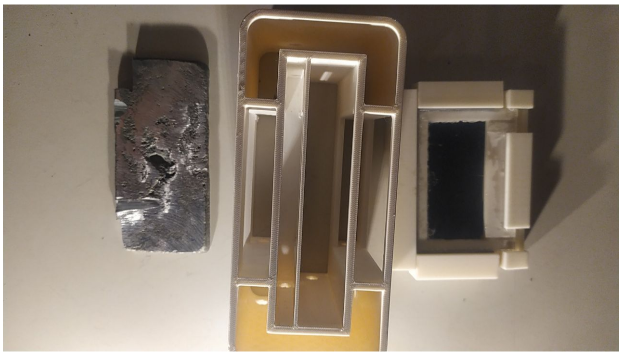

Figure 14: *Left: The new casted zinc anode; right: our new type of cathode holder*

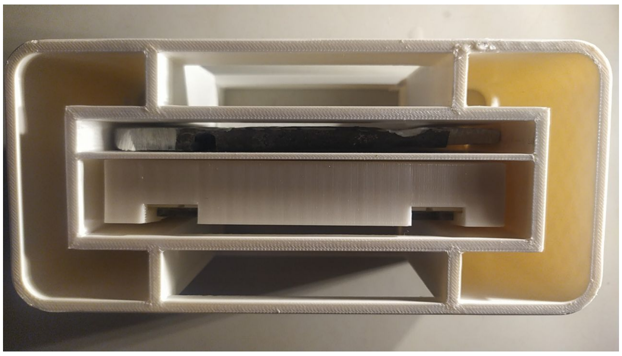

Figure 15: *Anode and cathode are placed into the chamber*

software k40-whisperer. Another famous software is called Lightburn, but this is proprietary software and expensive.

- the by far most important part is the GDE. We plan to produce GDEs once by our own, but at the moment we are happy to buy them from a german manufacturer named Gaskatel.

Assembly of the chamber

For the assembly of the chamber we need to assemble first the new cathode holder. This new device consist of two main plates with (selfmade) silicone-gaskets. At one of them the backside is an acrilic plate, so it can bewatched from outside what happens inside,

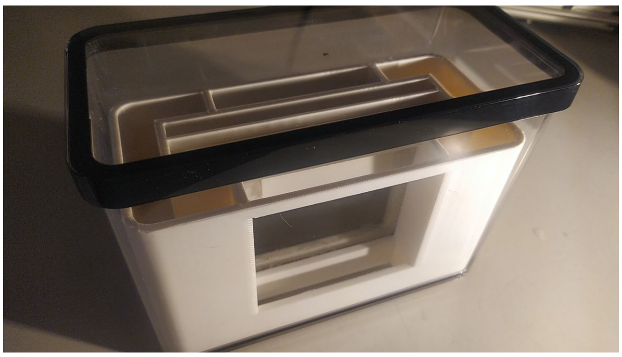

Figure 16: *The chamber fits exactly into a Rotho-box*

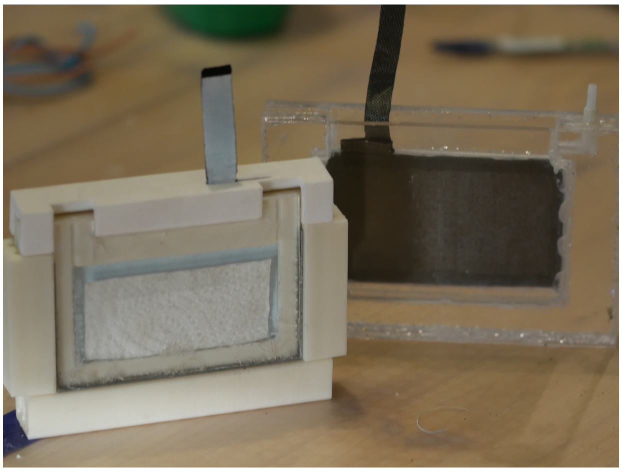

Figure 17: *For testing, the new cathod-holder has a piece of paper-towel inside for better recognizing any leakage*

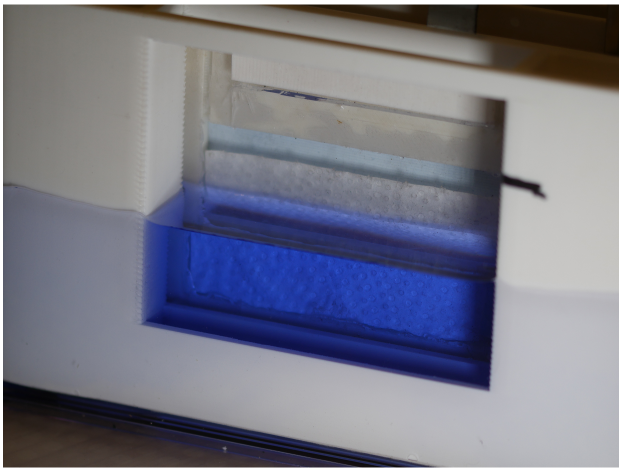

Figure 18: *The chamber is filled with blue water and the cathod holder is tight*

e.g. if there is a leakage and the cathod is drowning. Between the gaskets the GDE-layer is placed. Then 4 clamps hold the whole thing together, just like a sandwich.(see also figure 17)

The cathode-holder with the GDE is then placed into the 3d-printed chamber-part, and also the thick zinc anode. The whole thing then is placed into a Rotho box, which makes it possible to flood the chamber with electrolyte and further the box has a sealed lid. The lid has three conducts for tube-connectors for the electrolyte circulation and two conducts for the power-cables. If everything is in place and the lid closed the chamber gets flooded by starting the peristaltic pump and the circulation is initiated.

Cell testing

Befor use it's recommended to test the cathode-holder for potential leakage.

We did that with simple water, which we before coloured deep blue with some ink.

Than we assembled and sealed it with the gasket as usual but additionaly we added a piece of kitchen paper-towel to the air-cavity in the cathod holder. In case of a leakage this would absorb adn soak up the blue dyed water, which would start to climb up within the paper because of its capilarity. This can be watched pretty well from outside.

Results

Discussion

- wichtige Forschungsfragen: GDE-Lebensdauer, wirkungsgrad (hängt ab von x,y,z)

- comfortabel und Kosten ==> neuer gaskathoden-halter

Conclusion / Outlooks

- welche arten von experimenten könnte man machen ? zB. lebensdauer d. gaskathode, zb. verschiedene metalle testen

- open ==> verifizierung durch andere gruppe, zB. citizen science

- erweiterbar und modfizierbar ==> prototypern-evolution

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