Energy Storage in Bulgaria - Lead Acid or Lithium - Ion Chemistry

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Abstract — **The purpose of this paper is to formulate guidelines on the selection of battery chemistry for stationary renewable energy storage in relation to National Plan for Recovery and Sustainability of the Republic of Bulgaria, version 1.5 of 06.04.2022 [1]. The main technical characteristics of traditional chemical sources of electricity, lead-acid and Li-ion batteries are discussed.**

The main technical characteristics of traditional power chemistries, lead-acid and Li-ion batteries are discussed with the comparative review highlighting LTO and LFP as the most suitable among lithium chemistries and VRLA among lead-acid battery designs. LTO chemistry was rejected as potentially feasible due to its high cost.

Economic considerations are set out on the rationale for the selection of battery chemistry for RES for the period 2020-2030. The comparison of the two chemistries LFP and LA shows a marginal economic advantage of LFP towards 2020 with a trend towards increasing by 2030 due to the forecast in [4] of cheaper LFP technology in the coming years.

LFP technology has been recommended as the most promising for the construction of electricity storage facilities in Bulgaria, but without denying the future of LA chemistry.

Keywords—energy storage, chemical energy sources, battery chemistry comparison, selection of battery chemistry, RES.

I. INTRODUCTION

According to the "National Plan for Recovery and Sustainability of the Republic of Bulgaria" [1] published on 06.04.2022, it is envisaged to create a national infrastructure for storage of electricity from renewable energy sources (RES) named RESTORE [1].

The aim of the RESTORE project is to contribute to the full participation of RES in balancing the electricity system and meeting peak loads by building a national infrastructure of electricity storage facilities with a total charging energy capacity of 6000 MWh [1].

It is envisaged that the energy storage facilities will be distributed across the country close to renewable generation capacities [1].

In the energy system, RES with a minimum of 1.4 GW installed capacity together with the minimum required storage capacity should be integrated. This is part of the plan to commission a minimum of 3.5 GW of new RES capacity by 2026. Storage facilities should have a capacity for a duration of at least 4 hours and a capacity of at least 30% of the total installed capacity of the RES facility. For RES with an installed capacity of 100MWp, the minimum stored capacity is required to be 30MW or 120MWh for a lithium-ion battery [1].

It is not clear why only Li-ion batteries are considered, probably because they tolerate up to 100% depth of discharge (DoD), which simplifies the example.

The envisaged funds for the construction of a national infrastructure of electricity storage facilities, RES and batteries amount to BGN of 2 006 700 000 for 2022 – 2026 period [1].

II. BATTERY CHEMISTRIES WHIT A POTENTIAL FOR ENERGY STORAGE IN NEAR FUTURE

A. A Brief Overview

In recent decades, the application of electric batteries has grown exponentially, technologies have improved, and research and development has expanded potential chemistries [5].

The critical increase in carbon emissions and the emerging idea of a green and cyclical economy in Europe and not only, with intentions for a sharply increasing share of renewable sources of energy, contribute to this trend.

One of the promising applications of large and very large capacity electric batteries is related to electrical energy storage with the priority of predictability, reliability and sustainability of renewable energy sources [5].

What Chemistry to Choose in Bulgaria? The choice is determined by several factors. The optimal chemistry and price, the resources and technological capabilities to produce batteries, and the ability to recycle batteries at the end of their service life if we intend to develop a circular economy. The political and geopolitical factors are not taken in account.

B. Battery Chemistries

The most widely used chemical sources of electrical energy at present are batteries composed of individual cells in which electrochemical redox processes take place [3]. In this way, an electromotive voltage is generated between the opposite poles of the battery, and when an electrical load is switched between them, a significant direct current flows. If the chemical process is reversible, the battery is rechargeable; if not, it is only disposable [2]. There is active work on the mass application of flow batteries and metal-air batteries for instance lead-air [6] and the other more exotic chemistries.

This report focuses on the most widely used rechargeable lead-acid and lithium-ion chemistries listed in Table 1.

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TABLE I. CHEMISTRIES CONSIDERED

Abbreviation	Explanation
Flooded LA	Flooded lead acid
LFP	lithium iron phosphate
LTO	lithium titanate oxide
NCA	nickel cobalt aluminum oxides
NMC	nickel manganese cobalt
LMO	lithium manganese oxide
VRLA	valve regulated lead acid battery

C. Trends in The Near Future

Nowadays, the world is crazy about lithium batteries due to their indisputably high energy characteristics. Communication devices, hand tools, vehicles and all kinds of other electrically powered mobile products are flooding the market.

The trend towards electrification of transportation - electric vehicles (EVs) needs a huge amount of lithium batteries. On the other hand, static energy storage facilities (SESF) also need a huge amount of batteries. There is going to be a high demand for batteries, and when demand is high, prices rise. Projections by [4], [5] are for a significant reduction in the cost of lithium batteries by 2030 due to improvements in technology. A price reduction of a smaller percentage is also expected for lead acid batteries [4], [5].

But, how realistic are these forecasts in the face of energy war, higher fuel and energy prices and the costs of extracting, transporting and processing the raw materials?

Is the world capable of producing the required quantities of lithium and cobalt, are the reserves enough?

Will technologies be developed to recycle this metals efficiently to reduce the need for fresh raw materials?

Will the answer to these questions bring back lead-acid batteries for stationary energy storage because of the large lead deposits, simple production technology and their almost complete recyclability?

The questions are many, the predictions are there, but there are no definitive answers.

And in the end, does Bulgaria have the raw material and technical potential to produce needed lithium batteries and how are things with lead-acid for stationary energy storage?

Let's try to answer some of these questions.

III. TECHNICAL CHARACTERISTICS COMPARISON

A. The Calendar Life Comparison [5]

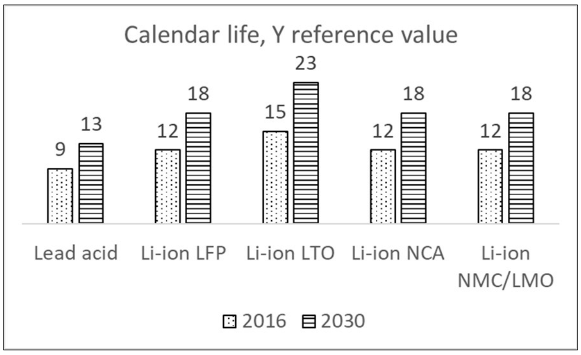

Fig. 1

It can be seen from (Fig. 1) that for 2016 the LTO chemistry has the longest lifetime, the other lithium chemistries are comparable, and the lead-acid chemistry has the shortest lifetime. The projected life by 2030 is inflated by 4 years for lead by 6 years for most lithium and by 8 years for LTO. In terms of calendar life, the favorite is LTO chemistry.

B. Cycle Life Comparison [5]

In terms of cycle live, the large advantage of LTO chemistry is impressive, both as of 2016 and as forecast for 2030, (Fig. 2). LFPs are second in the rankings, but with roughly half the prognostic lifetime of LTO chemistry. The other chemistries have a similar Cycle life.

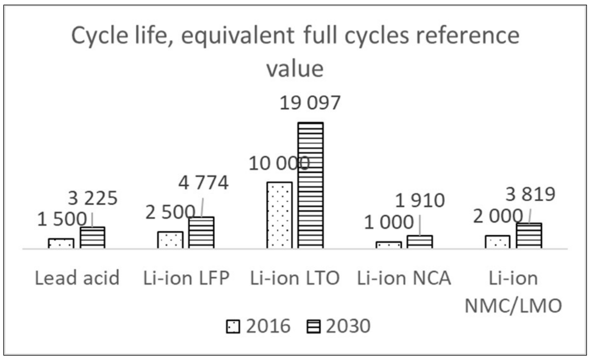

Fig. 2

C. Depth of Discharge (DoD) Comparison [5]

(Fig. 3) clearly shows that the lithium chemistries tolerate a DoD up to and above 90%, while the lead-acid chemistry only tolerate up to 50% - almost half.

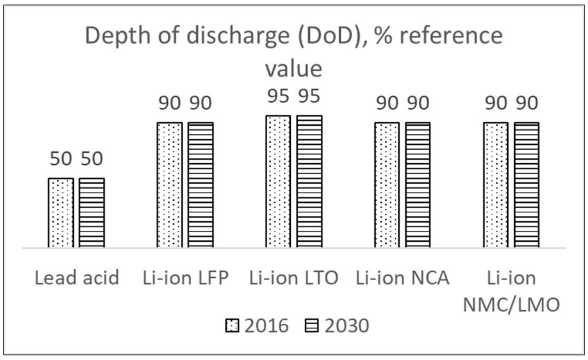

Fig. 3

D. Energy Density, Wh/L [5]

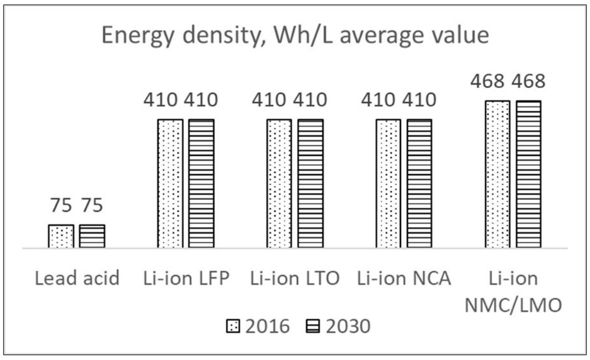

Fig. 4

In terms of energy density, no increase is expected up to 2030, (Fig. 4). The energy density of lithium chemistries is approximately between 400 and 470 Wh/L, while that of lead-acid is only 75 Wh/L, i.e. about 5,5 times lower.

E. Power Density, W/L [5]

Power density is also not expected to increase in the period to 2030. The power density of lithium chemistries is about 5000 W/L, while that of lead-acid is only 350 Wh/L, i.e. about 14 times lower, (Fig. 5).

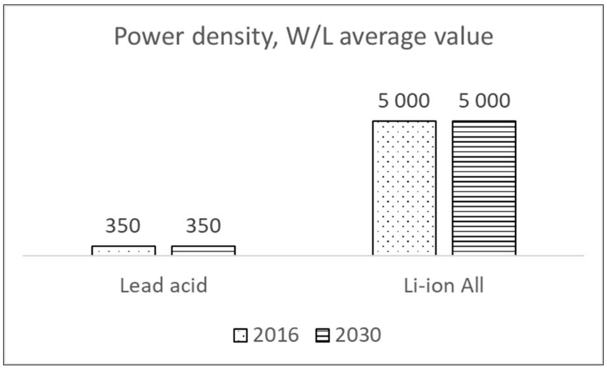

Fig. 5

F. Round Trip Efficiency, % [5]

By 2030, a small increase in round trip efficiency is expected, with a 10% difference between lithium and lead chemistries in favor of lithium (Fig. 6).

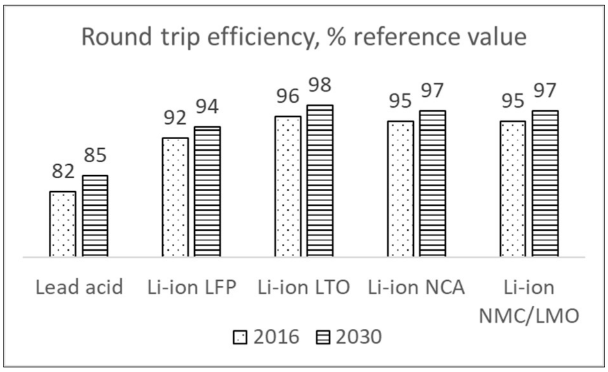

Fig. 6

G. Self-Discharge, % [5]

This technical parameter of batteries is not very significant in energy storage due to their frequent charge and discharge. It is the result of spontaneous electrochemical processes during prolonged open circuit storage without charge or discharge. (Fig. 7) shows that lead acid and NCA lithium batteries self-discharge faster, while LTO are the most stable.

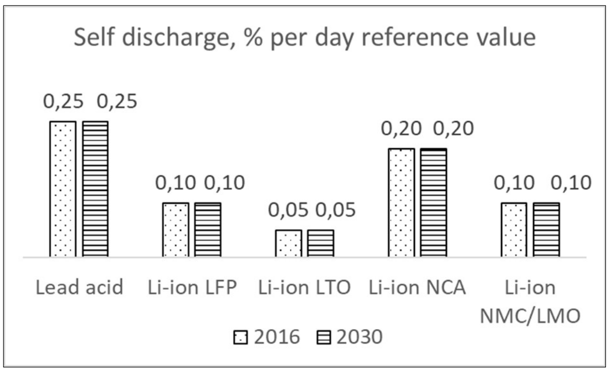

Fig. 7

The comparison of the main technical parameters of lead acid and lithium-ion batteries shows the well-known indisputable advantage of lithium batteries. Although for stationary energy storage some of the characteristics considered are not so significant, in terms of energy performance LTO and LFP batteries are the clear favorites.

IV. Operation and Safety

Valve regulated lead-acid batteries (VRLA) are maintenance-free (no topping up of the electrolyte is required). They are charged using simple protocols and simple chargers. Ideally, they are equipped with a Battery Monitoring System that monitors the state of charge (SOC) of each battery (group of cells in total) and minimizes the risk of overcharging, which leads to intense hydrogen evolution and the risk of forming an explosive mixture of hydrogen and air in enclosed spaces without ventilation. The result could be explosion. Lead-acid batteries tolerate relatively low and high operating temperatures, which naturally affect their performance, but without dangerous consequences.

Lithium-ion batteries are potentially dangerous - they explode and cause fires when overcharged or overheated. To prevent these risks, each cell is managed individually by a Battery Management System (BMS), forced cooling may be required. Charging protocols and chargers are more complex.

In terms of easier and safer operation, lead acid batteries are preferable.

V. Economic Considerations for Chemistry Selection

A. Installation Cost According to [5]

Aggregate battery storage unit cost data as of 2016 and projections for 2030 are shown in (Fig. 8). By 2030, battery cost across all regarded chemistries is projected to decrease by about 50%. LTO chemistry has the highest installation cost, followed by LFP, and the lowest for lead-acid chemistry. LTO is about 4 times more expensive to install than VRLA and LFP is over two times more expensive at the same unit capacity.

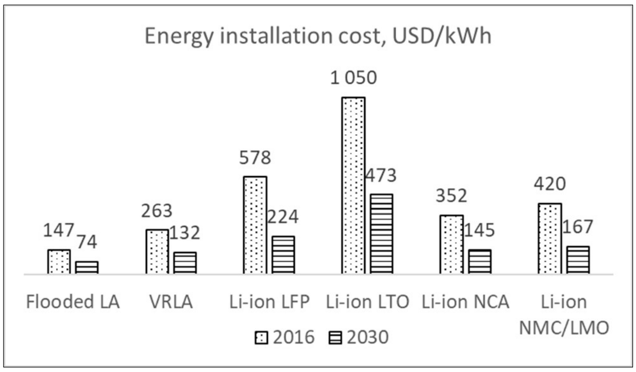

Fig. 8

Comparison to serviceable Flooded lead acid batteries increases the difference lead acid versus lithium batteries twice, but the periodic manual checking and topping up of electrolyte in each cell is a big disadvantage. However, Flooded technology may prove most feasible from a cost perspective in countries with low manual labor costs.

B. Installed PV and Wind single capacities in Bulgaria

The unpredictability of PV and wind generating capacities is the reason for the need to store the energy they produce to be used at the most appropriate time.

According to [7], the largest single PV units being 1x50 MW, 3x20 MW, and the rest up to about 5 MW.

According to the same source [7], the largest installed wind capacities are 2x78 MW, 1x60 MW, 1x50 MW, 1x35 MW, with the remaining larger ones up to about 20 MW.

Although significant new renewable capacity is planned to be installed by 2026 [1], it is not assumed to have a single installed capacity greater than that of existing capacity. The most climatically suitable sites have already been exploited.

In [1], batteries are required to have an installed capacity of 30% of that of the renewable generation capacity and be capable of supplying a rated load for a duration of at least 4 hours. It is easily calculated that the largest single energy storage facilities should have a capacity of around 20 MWh.

C. Installation Cost for Duration of at Least 4 Hours According to [4]

For this paper LFP is considered as the most promising lithium chemistry for energy storage, and among the unit capacities presented in [4] (1 MWh, 10 MWh and 100MWh), the closest to those required for RES in Bulgaria are 1MWh for small RES up to 5 MWh and 10 MWh for large capacities 20-80 MW respectively. The planned lifetime of the plant is 10 years.

Why is LFP lithium chemistry suitable for RES in Bulgaria?

- it is relatively cheap;

- achieves good energy density and power density, long cycle and calendar life, very good DoD and round trip efficiency;

- contains no cobalt, which is undesirable in the civilized world;

- phosphate and iron deposits are huge;

- contains no substances hazardous to the environment in its active mass.

Only a part of the extensive information presented in [4] has been selected for comparison in this paper according to the above criteria and comparable to the data in [5].

From (Fig. 9) it can be seen that the projections in [4] are for a marginal reduction in the price of lead-acid chemistry for the period 2020-2030, while for LFP li-ion chemistry a reduction of around 40% is expected. The increase in plant capacity does not lead to a significant reduction in the installation cost of the storage block.

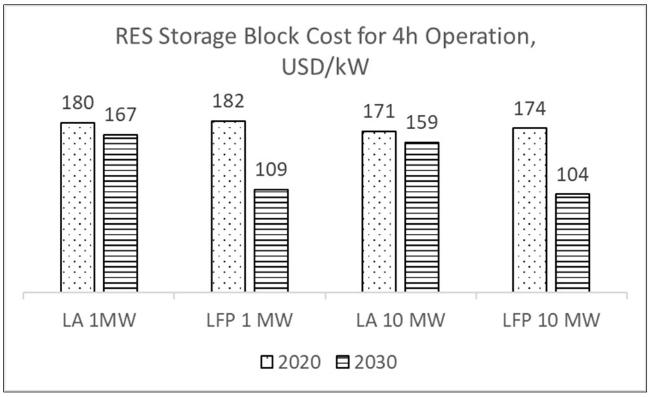

Fig. 9

At first glance, a paradox emerges. According to [5] Figure 8, the cost of LFP chemistry is 2-3 times higher than that of lead-acid, and the cost of LFP storage block is about 35% lower than that of LA Storage block [4] (Fig. 9). The explanation of the "paradox" lies in the values assumed in the analysis of [4] for cycle life (Fig. 10) (about three times higher for LFP versus LA) in contrast to [5], (Fig. 2) and tolerated DoD (about 40% higher for LFP versus LA chemistry) (Fig. 3). The clue is in the lifetime of the energy storage system (ESS), which is set to 10 years in [4]. Assuming one cycle per day, lead-acid batteries would need to be replaced fully 5 times and lithium batteries only 2 times. More than 2,5 times as many lead batteries as lithium batteries will be needed for the planned service life.

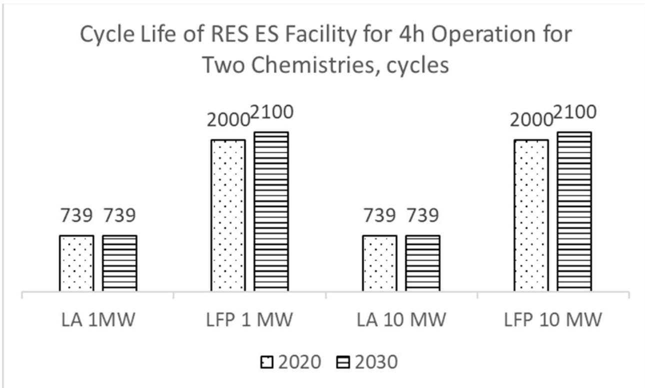

Fig. 10

Several comments can be made on (Fig. 11):

- the total cost of RES energy storage (ES) facility expressed by the cost of electricity in USD/KWh is comparable for the two technologies with a marginal advantage of LFP chemistry;

- LFP technology has a more pronounced cost reduction trend in the period 2020-2030 compared to LA due to the assumed 40% cost reduction of LFP technology in the period 2020-2030;

- the increase in the scale of the RES ES facility from 1 to 10 MW does not drastically affect the cost of the value of the facility in terms of the price of electricity.

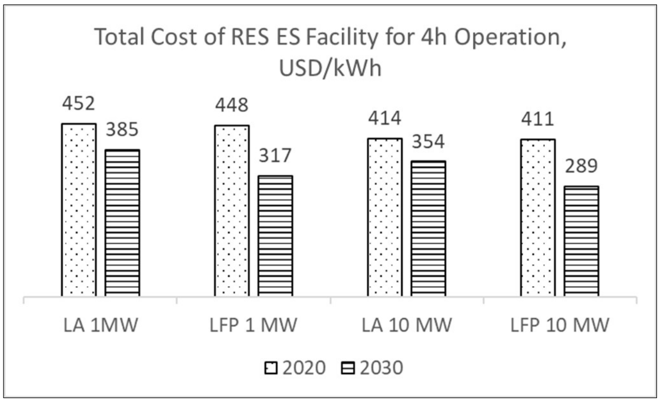

Fig. 11

The other generic criterion for a comparative assessment between two investments is the Total cost of the facility expressed by the unit cost of installed capacity USD/kW (Fig. 12). The data presented in [4] show a marginal advantage of LFP chemistry for 2020, but for 2030 this advantage is much more pronounced, again because of the assumed reduction in the cost of LFP technology at the end of the period considered.

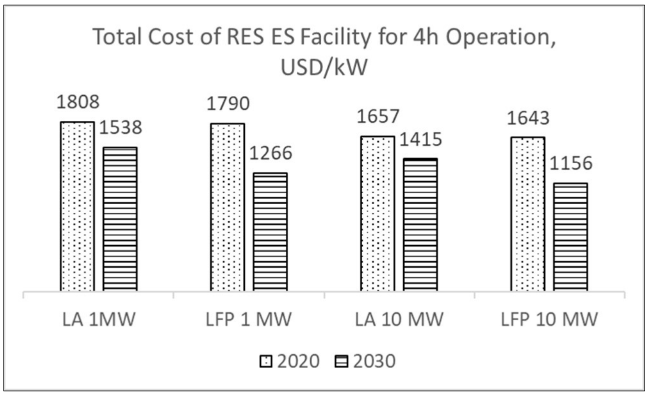

Fig. 12

VI. Conclusions

Looking at the data from the two authoritative sources [4] and [5] at first sight leads to confusion. It turns out to be cheaper to build a 1-10 MW RES energy storage utility based on the more expensive LFP than based on the cheap LA chemistry. What's more, the pricing scissors are forecast to open in favor of LFP chemistry by 2030. There are ideas for using second-hand Li-ion electric vehicle (EV) batteries for RES energy storage. This would likely reduce the cost of the RES ES facility based on LI-ion chemistry further, and the LA chemistry would fall out of the ranking entirely. There is the possibility of a breakthrough in lead chemistry through the commercial application of lead-air chemistry, which is still considered experimental.

But, for now, optimal recycling technologies as materials for LI-ion batteries have not been developed, and in view of the huge amount needed for RES and EVs in about 10 years, serious environmental problems can be expected, and governments solve such problems with restrictions and eco-taxes. Who knows how the accounts would come out then, but for now the outlook is for the rise of lithium and the decline of lead chemistry.

The risk of explosions and fires in large energy storage installations is not excluded for both technologies. When choosing the optimal one, this risk must also be reasonably assessed depending on the specific conditions.

To the question what chemistry Bulgaria should choose for RES ES system, the answer at the moment is LFP, but do not abandon the possibility of using LA chemistry, especially if the batteries are own production and the budget for this is over 2 billion.

Acknowledgment

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

References

[1] National Plan for Recovery and Sustainability of the Republic of Bulgaria, version 1.5 of 06.04.2022, https://nextgeneration.bg/14.

[2] Allen J. Bard György Inzelt Fritz Scholz (Eds.), Electrochemical Dictionary, 2008 Springer-Verlag Berlin Heidelberg, ISBN 978-3-540-74597-6.

[3] Detchko Pavlov, Lead Acid Batteries: Science and Technology, 2017 Elsevier B.V., Second Edition, ISBN: 978-0-444-59552-2.

[4] Kendall Mongird, Vilayanur Viswanathan, Jan Alam, Charlie Vartanian, Vincent Sprenkle*, Energy Storage Grand Challenge Cost and Performance Assessment 2020, Pacific Northwest National Laboratory, US Departmat of Energy, Technical Report, Publication No. DOE/PA-0204. https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf.

[5] Pablo Ralon, Michael Taylor, Andrei Ilas, Harald Diaz-Bone, Kai-Philipp Kairies, Electricity Storage And Renewables: Costs And Markets To 2030, International Renewable Energy Agency (IRENA), 2017, ISBN 978-92-9260-038-9.

[6] Yovka Milusheva, Iliyan Popov, Boris Shirov, Krum Banov, Reneta Boukoureshtlieva, Willy Obretenov and Vesselin Naidenov, Lead-Air Electrochemical System with Acid Electrolyte, Journal of The Electrochemical Society, 2021, Volume 168, Number 6, doi: 10.1149/issn.1945-7111, online ISSN: 1945-7111.

[7] Public register of installations for electricity production from renewable energy sources (RES), https://www.veiregistar.bg/index.