Thoughts on the improvement of lead-acid batteries – in light of the expectations of the latest international trends

The **United States Department of Energy (DOE)** laid down directives on the vision of energy storage in December 2020.
These directives were reflected in the summary report prepared jointly by two significant American associations of the battery industry, **Battery Council International** (BCI) and **Consortium for Battery Innovation** (CBI), issued in June 2021, establishing concrete targets and goals for the energy strategy of the near future.

It is evident that the European battery industry community, **EUROBAT**, has quite similar directives, including the same requirements and expectations.

Without describing these in detail, I would like to highlight some common elements which may have a decisive influence on the future of energy, with particular emphasis on energy storage through lead-acid batteries.

Both documents emphasize that initial investment costs and particularly favourable recycling rates grant a prominent role to lead-acid batteries, and the further improvement of some characteristics may significantly strengthen this role and expand the fields of use of these batteries.
This is supported by statistical data: the new generations of lead-acid batteries could be seen in a fairly favourable light if they fulfil certain conditions.

Let's focus on this! Allow me to expound some thoughts to set the future of lead-acid batteries on a favourable path.

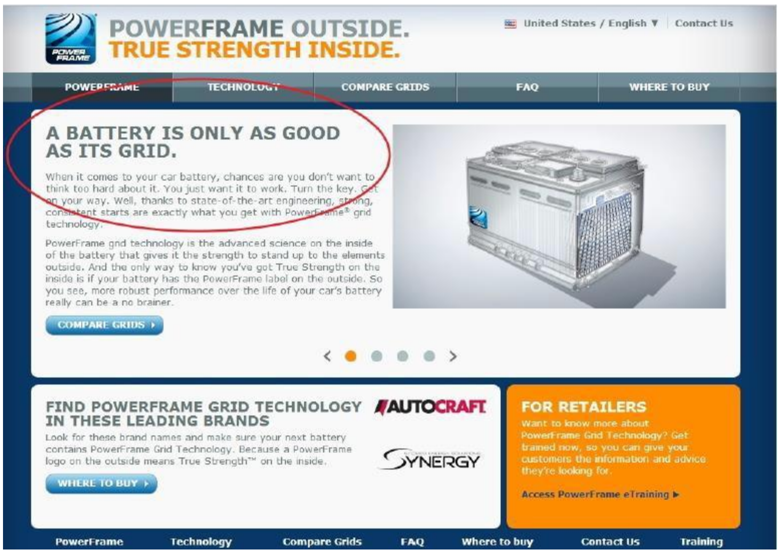
I would like to highlight a specific table of the American report, which allows the accurate demonstration of almost every important factors.

Performance Category	Current	Target
Cycle life (80% DOD[1])	4000	5000
Cycle life (100% DOD)	2000	3000
Round Trip Efficiency (%)	82	88
Acquisition Cost ($/kWh)	~135	35
Operating cost ($/kWh/cycle)	0.09	0.025

These important factors are **performance**, **increasing cycle life** and **cost reductions**.

The targets in the table are clear. If we expand these targets with expectations – primarily formulated as technical questions –, which also arise as constant demands (performance increase per unit mass, reduction of charging times, better conformance with the "circular" manufacturing-recycling system of lead), **we will get a vision focusing on the key element of lead-acid battery manufacturing: the lead grid**.

If we take the often-quoted, but still "everlasting" image published by Synergy (previously: Varta), it is obvious that **the technical basis of the quality and usability of classical lead-acid batteries, as well as the economical basis shaping the related financial processes is the lead grid used**.



If we examine how each characteristic of the batteries depend on the grids used, it will become clear, what development actions will help to achieve the expected targets.

Some of the present-day lead-acid batteries use cast grids. To make the base material suitable for casting, it should be alloyed, mainly with antimony (Sb). This procedure does improve metallurgical characteristics, however, intercrystalline discharges occur when contact is made with the electrolyte, which damages the lead and forces it to discharge itself.
For this reason, the application of this solution shows a constant decline.
It should be noted that grids made with high-pressure die casting used in traction batteries – the design of which is far from optimal – are similar, but the same issues rarely occur due to regular examinations and lead surplus; instead, these batteries have the issues of limited electrochemical surface area, unreasonably strong internal resistance and excessive use of base material.

Expanded grids spreading from the middle of the previous century are more advanced. The base material of this also requires a solute for processability, and this is calcium (Ca).
Calcium eliminates tendency for self-discharge, however, the emergence of calcium sulphate (gypsum) still results in an adverse effect.

However, the worst disadvantage of these grids is not this, but the unreasonably strong internal resistance, sub-optimal electric current paths and the related undesirable base material surplus. Nevertheless, these are the most widely used grids. These grids are used in AGM batteries, which “do not need maintenance” and therefore are favourable for the users, but are controversial in technical aspects.
These are not bad batteries, their use is simply limited, and lead-acid batteries can be used significantly more widely if their parameters are improved and their well-known sources of errors are eliminated. We shouldn’t forget that **we are talking about a technology more than 70 years old**, which started a revolution in automotive industry when it appeared…

I will return to the problematics of alloys and grids as a key issue in detail later on.

There are some notions and improvements for the complete transformation of the structure of lead-acid batteries, which could be successful. These paths, however, could be unreasonably expensive and complicated, which does not necessarily rule out their effectiveness, but complete structural transformation would clearly require a complete factory reconstruction, the economic parameters of which are unknown.

On the basis of the needs formulated, **it would be a better and economically much more reasonable first step to manufacture batteries built in the classical way, with grids reliably eliminating currently existing errors**.

Since this would require changing the grids only, the other manufacturing systems of battery factories would remain unchanged.

What opportunities do we have, and which issues do these opportunities remedy to facilitate making batteries with better conformance with the needs set out?

One of the sources of errors is the materials used

The selection of materials determine which production technology may be used.
Chemical reactions (charging and discharging) need lead, lead oxide and electrolyte (sulphuric acid). Everything else would only disrupt this process and have adverse effects on both cycle life (cycle count) and "Round Trip Efficiency" indicator.

Alloying would also make production technology more complicated, and lead alloys are evidently more expensive (…making the method and costs of recycling more complicated and expensive).

The method and costs of recycling should always be addressed because we are talking about complex circular technical-economical processes!

The greatest issue of lead alloys – where alloying makes the lead processable – is the fact that alloying is required to make the production technology of lead grids suitable for mass production, but grids manufactured with this method would also manifest other sources of errors.
These errors are genuinely limiting the usability of batteries. **The production technology of grids determines specific performance level and the general quality of batteries.**

Internal resistance

The currently mass-produced grids are made with a **sub-optimal grid geometry** due to the production technology (expanding).
Neither electric current paths – essential for energy in- and output – **are modelled**, nor the expected conductor cross sections are optimised.
Not even the joint application of "uniform" shapes (and excess use of material) can keep the internal resistance so low that it would prevent local overheat during use, which, in critical cases, may result in local breaking of the grid structure, possibly initiating a chain reaction leading to breakdown. **Relatively strong internal resistance clearly reduces the efficiency of the stored energy, as a significant part of the energy converts into heat.** The heat could also result in the continuous loss of electrolyte (evaporation), making it important to reduce this heat. This can be achieved simply through limiting its source by minimising internal resistance. (Optimised electric current paths)
This cannot be achieved through the unreasonably excess use of materials, but through drastically redesigned grid geometry and reasonable use of materials.
In case of the same electrochemically active surface area (and performance), **proper design and suitable production technology could save nearly 50% of the material (lead)**! (Grid weight of 35-40 g instead of the usual 70-80 g.)

Electrochemically active surface area

Electrochemical processes occur on the contact surface of reagents in the presence of electrolyte. The more (electrochemically active) surface area is available, the more efficient the reaction will be.
In case of batteries, this characteristic is measured by the amount of energy removed per unit time in case of energy output, whereas, in case of energy input (charging), it is measured by the amount of charging power used and the related charging times.
Another interesting metric is power surge tolerance, that is, the extremes a battery can endure per unit time.

The same metric would also suggest the thermal sensitivity of batteries, as low cold tolerance is mentioned often among the negative characteristics of lead-acid batteries. This, however, could only partially be attributed to the solidification of the electrolyte: limited electrochemically active surface area is much more important, because that is where the reaction occurs…
In case of expanded grids, this is not so good currently, we could find much more efficient solutions. **Grids should therefore be redesigned to have a shape that allows the available reactants to contact with the largest possible electrochemically active surface area.**

Crystal structure

This is not the most important characteristic, but it still should be mentioned that due to the technology used throughout the manufacturing of expanded grids, there are some "sensitive" voltage concentration spots in the crystal structure, which would also reduce cycle life and cycle count. **If we decide to use a different grid manufacturing procedure, that should organise the lead into a uniform and homogenous crystal structure.**

Mass adhesion

It must not be neglected in case of batteries subject to vibration, whether the applied lead oxide mass has a reliable adhesion to the grid structure. This is another factor influenced by thermal dilatation movement resulting from the previously mentioned local overheat, and mass adhesion could also be controlled through the production technology of the grid.
With regard to mass adhesion, expanded grids are not ranking the highest, as better solutions do exist.

Environmental protection

In case of the technology used currently, the base material is in liquid form when it contacts the ambient air, which is dangerous and harmful.
There are grid manufacturing technologies where the liquid lead is kept in a closed space, preventing environmental pollution.

Conformance with the "circular" cycle of lead

The "circular" cycle of lead currently involves unreasonable logistical steps, unreasonable waste of energy, and not every element of the cycle is in conformance with the current requirements of environmental protection. The elimination of these could make the process simpler, cheaper and more efficient, and could also reduce environmental impact significantly.

When developing the **Blewin battery system**, it was of utmost importance to **eliminate as many "problematic" factors of the grids**, and of other technical aspects of the batteries, **as possible by applying solutions better than any other available currently**, even if it means manufacturing with a system based on completely new procedure(s), but also capable of mass production.

Measurements have proved that the parameters of the manufactured batteries would often differ from the usual parameters in a positive direction, and that these differences would also manifest at business level.

- **20-30% of the base material** (lead) can be saved per each battery. Thus, we don't have to purchase, manufacture or recycle this material, which means that this is a saving at the level of material, energy, machine hours and salary at the same time, and we also have a non-polluting technology as a bonus.
- **No heat produced** when charging, and **no acid fumes emitted** during operation.
- **Charging times** are below 40% of the usual (depending on charging power).
- Significantly **less vulnerability to cold**.

- Using **pure lead** as base material **prevents sulphation**, even under demanding and extreme use. (**Cycle life!**)
- **Outstanding mass adhesion.**
- **No vulnerability** to and no damages by overcharging and deep discharging.
- The test results of batteries built with grids manufactured on the basis of the know-how show a specific performance-weight value over **80 Wh/kg**.
- The manufacturing processes of grids and batteries using the Blewin system **minimise environmental pollution**, resulting in practically **no lead fumes emitted** during the process, and the amount of energy required is lower than usual as well.

Batteries using the Blewin system were not mentioned because the system solves everything immediately… **The system merely points towards the right direction…**

This is simply about a systematic improvement resulting in a grid suitable for mass production, and about an existing and available battery manufacturing know-how.
This know-how tried to eliminate the (continuously persisting) weak points of lead-acid batteries and the environmental pollution subsisting constantly throughout the processing of lead way before the demands presented herein would have occurred. The principle used to make the lead grid won silver medal at the International Exhibition of Inventions of Geneva nearly 25 years ago…

Today has the world economy reached the level of demands in the field of energy storage where **using this know-how is considered a reasonable step**, because this know-how shows results that may, **in a tested manner**, ensure and support improvement and a series of demands for improvement declared herein.

The existing elements and results of the improvement could be part of the recently emerging renaissance of the new generation improvements of lead-acid batteries, and of **the international or national energy strategies based on such improvements**.

These could make the "circular" economic cycle of lead into a simpler, cleaner and more efficient process. If a technical solution, making the recycling process simpler, cleaner and more reasonable, would be integrated in this process, that could **increase the achievable economic results even further**.

July 2021

Tamás Mészáros dr.

Sources used:

Energy Storage Grand Challenge Roadmap December 2020 (U.S. Department of Energy (DOE))
LEAD BATTERY GRAND CHALLENGE EXECUTIVE SUMMARY (BCI, CBI 2021)
Battery Energy Storage in the EU (Eurobat 2016)