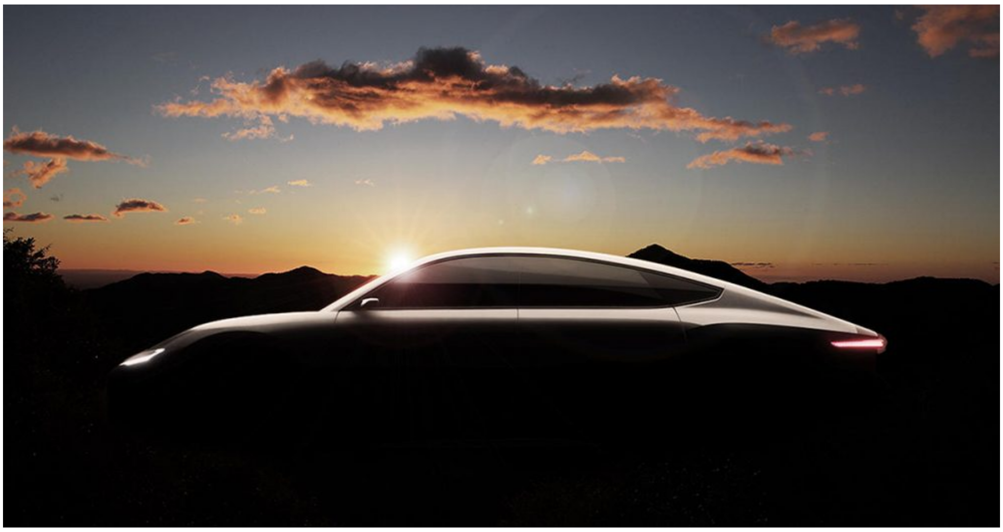

Energy storage for Solar Electric Vehicles

white paper

This essays aims to be an authoritative report that informs you concisely about this complex issue and presents our philosophy on the matter. It is meant to help you understand this issue or make a decision.

This concept aims at an insight on the technological solution for the battery-based energy storage of Solar Electric Vehicles (SEV's). As example we take the Lightyear One.

1. Starting points energy storage SEV's

Not much has been published about the specifications of SEV's till now, and therefore the starting points for energy storage will be assumptions.
From informal sources and discussions and interpretation of the data following assumptions can be made:

- weight is an issue. Central of the development strategy of the SEV often is about the weight circle. Less weight means less energy consumption, which enables lighter constructions, reducing weight et cetera.
- volume is less important. The LO1 for example is a big car with a flat surface.
- range should be about 800 km's: compared to the Tesla S the LO1 will be significantly lighter (1250 vs 2100 kg), will have a better drag coefficient (< 0.2). Efficiency could be twice as good, battery capacity therefore might be about 60 kWh.
- as SEV's promise a reasonable acceleration times and on the other hand low energy use at constant speeds specific power doesn't have to be as high as cars like Tesla.

2. Battery requirements

EV battery storage in general

Electrochemical storage devices used in EV must fulfil certain requirements, so that the EV can perform in a satisfactory manner. The key requirements in general are:

- high specific energy: satisfactory range,
- high specific power so that drivers acceleration expectations can be met,
- long, maintenance free lifetime,
- safe operation under a wide range of conditions,
- end of life disposal has minimum environmental impact,
- high efficiency in charge and discharge cycles.

Typical EV Battery Electrical Parameters and number for current BEV's are Power (> 80 kW), Energy (25 – 100 kWh), Voltage (200 -1000 V)

SEV LO1 Battery Parameters
Not absolutely complete:
- Nominal energy capacity (E_{nom}, in Wh or kWh): the maximum amount of electrical energy that can be extracted from a fully charged battery state to the empty state. With the declared commitment of +800 km range, the LO1 will need 60 kWh (efficiency 2 times comparable Tesla's).
- Nominal voltage (V_{nom}, in V): rated voltage of the battery when it is fully charged. When a battery is discharged or is loaded, the voltage reduces gradually to a lower value, Vbatt. In order to gain efficiency or reduce losses, the LO1 needs a high Voltage, suppose 1 kVolt.
- Nominal power (P_{nom}, in W): rated power of the battery for charging or discharging derived as a product of the nominal voltage and current of the battery. For the LO1 50kW might do.
- Energy density or specific energy (Wh/L or Wh/kg): It is the capacity of the battery per unit volume or unit weight. For the LO1 we choose for volume instead of weight.
- Charge/Discharge rate (C-rate): It is the ratio of the magnitude of current drawn/fed to the battery, to the nominal ampere-hour of the battery. This needs further research how to optimize these conflicting perspectives. As the LO1 will not be a 'power-SEV' an outstanding acceleration and therefore C-rate won't be necessary.

Hybrid energy storage
One method of achieving electrical energy storage with a high specific power is to use ultracapacitors (UC). The use of UC's alone would not suffice, as these components display poor specific energy characteristics. The ideal solution is to use a hybrid energy storage method in a parallel configuration. This would combine the high specific power density of UC's with the higher specific energy of an electrochemical battery.

3. Batteries and active materials

Categories of batteries
From literature (by Van den Bossche and Westbrook) mainly 5 categories of battery active material count: lead acid, nickel based (NiMH), NiCad, high temperature (Sodium-nickel-chloride (NaNiCl or Zebra)), lithium based (Lithium-ion (Li-ion) and Lithium-polymer (Li-poly)) and metal air (Aluminium air (Al-air) and Zinc-air (ZN-air)).
Because of the weight and temperature the Lithium varieties have advantages above the other categories.

EV Lithium battery types
As stated, Lithium based batteries are classified by the type of active material. Two main types exist, those with liquid (Li-ion-liquid) and those with polymer electrolyte (Li-ion-polymer). The Li-ion-liquid type is generally preferred for EV applications. Within the Li-ion-liquid type, there are three lithium materials, lithium cobalt (or lithium manganese oxides), lithium iron phosphate and lithium titanate.
- Lithium manganese ($LiMn_2O_4$) offers a potentially lower cost solution. It has been largely studied for electrical vehicle application, especially in Japan. The drawback of this type of battery is the poor battery life due to the slight solubility of Mn.
- Lithium iron phosphate ($LiFePO_4$) batteries are manufactured by many companies in the world and have gained credibility through their use in power tools. Lithium iron

phosphate cells have a much lower energy density than standard format cells, but can be charged much faster—around twenty to thirty minutes. Moreover, LiFePO4 has been recently considered that it features an improve stability on overcharge which is good for safety, a very high power and has potential for lower cost because they use iron.
- Lithium titanate allows charging on the order of ten minutes and have been shown to have an extremely long cycle life - on the order of 5000 full depth of discharge cycles. Lithium titanate has high inherent safety because the graphite anode of two other batteries is replaced with a titanium oxide.

The LO1 will have a Li-ion-liquid type battery. Further investigation will show whether this will be LiMn2O4 or a Lithium titanate.

4. Battery Management System

When cells are connected in a series or parallel configuration as in a battery pack, management and control of the charge and discharge conditions becomes crucial to extend the lifetime and limit ageing effects of individual cells.
A battery management system (BMS) is used to monitor, control and balance the pack. The main functions of a BMS are outlined in the figure below. Without balancing the battery pack, the battery is not only risking unnecessary damage, it is also operating sub-optimally. Because the worst cell is limiting the performance of all cells in the battery pack, it is very important to prevent big differences in cell's state of charge.
Because the performance of battery cells varies with temperature, it is therefore crucial to include a thermal management system in the battery pack. This ensures all cells are both electrically and thermally balanced and the lifetime will be extended. Thermal management systems can either use air or liquid as the transfer medium. For integrating into the vehicle, the power consumption must be low and it must not add much additional mass. The thermal management system can realize its performance requirements using either passive or active means. A passive system using only the ambient environment may provide sufficient thermal control for some battery packs whereas active control may be required for others.

It is clear that the BMS, through balancing, thermal management and control of voltage and current helps in improving the battery life. Another important factor that can improve battery life is to reduce the number of charge-discharge cycles and the maximum depth of discharge. The battery should not be completely charged and discharged, because this is detrimental to battery life.
In respect to the LO1 is the option to limit the power output of the car, which limits the discharge rate of the battery. This has the downside of having lower acceleration, but while the LO1 will not be designed for best in class acceleration, there's more battery life to gain.

So the battery management system is important. The BMS has the possibility to monitor and control (directly or indirectly) several different parameters of the battery: voltage, current, state of charge, temperature, state of health. For the LO1 the BMS is even more important because of the ambition to set new standards for efficiency.

Literature

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