EUA-EPUE
European Platform of Universities in Energy Research & Education

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EUA-EPUE Response to SET-Plan Consultation

Key Action No. 7: "Become competitive in the global battery sector to drive e-mobility forward"

BACKGROUND

This response provides the perspective of the European Platform of Universities in Energy Research & Education (EUA-EPUE) to the consultative process on the European Strategic Energy Technology Plan (SET Plan) - Key Action No. 7–"Become competitive in the global battery sector to drive e-mobility forward".

EUA-EPUE responds to the consultation from the perspective of the universities' role in society. Universities constitute a significant part of the research capacity in Europe. At the same time, they educate the highly skilled work force of our societies. We consider therefore that setting up the SET-Plan projects with ensured integration of innovative research with education, including industrial partners, will provide a high pay-off towards achieving the energy system transition, which is a major objective of the SET Plan and the European Union.

RESPONSE

Proposed targets in Key action No 7 "Become competitive in the global battery sector to drive e-mobility forward"

For the main expected outcome: To make specific recommendations on the priorities/targets proposed in the issues paper(s)

- Do you agree with the targets set in the issue paper?
- Do you think that the level of ambition is correct?
- Are there any standing issue(s) in the way to reaching the proposed targets/priorities?

It may be useful to understand the broader context in which these targets/priorities need to be achieved. If possible, we suggest that the following is addressed as well:

- *What are your specific recommendations on prioritising R&I activities on these issues (and building where appropriate on relevant existing initiatives)?*
- *Who are the best placed actors to implement the targets/priorities (Industry, EU, Member States, regions, groups of countries/organisations/etc.)?*

COMMENTS ON THE TARGETS AS LISTED IN TABLE A) PERFORMANCE TARGETS

a) There is a strong focus on lithium ion technology in the targets, which is in line with the record energy densities of these batteries. Research in academia is strong in Europe in this area, while industry is mainly outside Europe.

b) The targets focus on batteries for automotive sector, and limit to high gravimetric and volumetric energy density batteries for inside the Electric Vehicle (EV). However, once charging stations are part of the scope of e-mobility, also static batteries next to fast charge stations for EV might be anticipated for, were eventually supercapacitors may play a role as well. This is because high charge rates of many kWh batteries require high peak power capabilities that can often not be drawn from the local grid connections. Stationary batteries may be able to provide this peak

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power. Such static battery does not need to be based on the light lithium battery technology but can be based on lower cost solutions. Volumetric energy density may be 100Wh/l, 175Wh/L, 250 Wh/Lin 2015, 2020, and 2030.This might be Li, Na, or H based batteries optimised for cycle life and calendar life rather than energy density. Such batteries are also necessary for general grid storage services.

Target 1*Gravimetric energy density*

a) Pack level energy density is related to cell level energy density, packaging, cooling and to the electronic BMS system. There is an inter-dependence on the targets for charge rates via the cooling requirements; the higher the charge rates the larger the demand for cooling, which will increase weight and volume of the pack. As stated above, there should also be considered lower energy density low cost static batteries with application next to EV fast charge stations where multiple EV can be fast charged.
b) Cell level. The target of 400Wh/kg implies that at a high cell potential of 4V one requires to store 400/4 = 100 Ah/kg. For a high voltage spinel and a C anode this requires reaching the theoretical energy density, excluding current collectors, electrolyte, binders, additives, and packaging. The increase in energy density indicates that the current Li ion materials will be replaced by higher energy density and more novel chemistries, like lithium sulphur batteries, and/or silicon anodes, in order to reach these high energy densities. It is very challenging to have this transition in combination with the target 6 on cycle and calendar life. Results in industry still show too fast declining cell capacities. Therefore, it would be more realistic to have a cell level target for 2020 reduced to below 400 Wh/kg. It is further stressed that the targets cannot be reached simultaneously. Even with the novel materials combination of Si/Li-rich systems using thick electrodes, will not meet 700 W/kg, 1000 cycles and 15 years life in 2020. For post-Li-ion technologies, only Li-S could achieve 400 Wh/kg, but not with 700 W/kg, 1000 cycles and 15 years life. 400Wh/kg may be achievable in 2025.

Target 2 *Volumetric energy density*

a) Same remark as above under 1a.
b) Same as above.

Target 3 *Gravimetric power density*

a) Increasing energy density and power density at the same time is extremely challenging because the high power density normally requires more current collectors, electrolyte and conducting additives. Instead of obeying both density and power demands one optimises one or the other.
b) Same as above 3a.

Target 4 *Volumetric power density*

a) Same remark as above under 3a.
b) Same as above 3b.

Target 5 *Fast recharge time*

The charge rate targets mentioned are not consistent with the energy and power density targets. For instance 70% of 400Wh/kgcharged in 0.25h means a power density of 0.7x400Wh/kg /0.25h = 1120 W/kg which is larger than the target of 750W/kg. Target of 3 minutes is also inconsistent: 0.7x400Wh/kg /0.05h = 5600 W/kg which is much larger than the power density target.

The question is what the actual targets should be. When considering the increasing size of EV battery packs, and the increasing driving range that those correspond to, a fast charge time of 20 minutes may be considered optimal when also considering the necessity for pause of the driver. In that case a 0.8x400/0.333 = 960 W/kg suffices for charging to 80% in 20 minutes. One should then realise, however, that one requires more fast charge stations in order to be able to charge the same number of cars because each fast charger is occupied for 20/3 ~7 times longer time. One would possibly require 7 times faster charging connections or more on high way stations than current gas lines on the same stations. In addition, fast charging is detrimental to the battery cycle life and calendar life, then very fast charges (e.g. in 3 min) are unrealistic as they would degrade the battery rapidly.

Target 6*Battery life time*

a) - Cycle life to 80% DOD. 1000 cycles for an EV battery may be rather excessive when the battery would enable a range of 500km. When an EV is built with a battery that provides a range of 500 km, 80% means 400km between charges. 1000 of such charges means the car runs for 400.000 km, which is a life time of 20 years of the car when it drives 20.000km a year.
- For a Plug-in Hybrid Electric Vehicle (PHEV) with a range of 40 electric km (an average range for a EU car on a day) 1000 cycles are too little because that means the car will lose its EV capabilities after ~40.000 km.
- For a Hybrid Electric Vehicle (HEV) 1000 cycles is much too little, since these are mostly utilised for short charge and discharge periods during few km and braking and accelerating.
- There is a strong interdependence with charge rates and heating effects in the battery and therefore with degradation. The faster the charge, the more heat evolution and the faster degradation.
- For a static battery next to a fast charging station much larger numbers than 1000 charges will be required because it needs to supply charge to many EV in a day, possibly 100 EV per day during 20 years which equals 20 x 365 x100 = 730.000 times the typical EV battery charge. Such large cycle numbers are only reached for extremely robust batteries that are not reaching maybe 20% Depth of Discharge (DoD) (i.e. the static batteries are much larger capacity than the EV batteries).

b) Calendar life. Tesla appears to guarantee 10 years for calendar life. The guaranteed capacity may be reached, however, by having a higher active electrode mass in the system, i.e. a lower energy density and DoD. This hides the capacity loss of the battery materials.

COMMENTS ON THE TARGETS AS LISTED IN TABLE B) COST TARGETS

a) Cost of the technology depends on raw materials cost, processing, Battery Management Interface (BMI). The driver to high energy density Li ion batteries works e.g. towards lithium sulphur chemistries where the active materials cost is low, but the electrolytes and Li become relatively larger fraction of the cost. Raw materials cost will also remain in the copper and wiring of the Battery Management System (BMS).

b) There should be different targets for EV batteries (light high energy density) and for static batteries for application near fast charge stations (durable, low cost).

Target 1 ***Battery pack cost for automotive applications***

For academics the cost level of battery packs comes from model sources rather than insight from inside the industry. Targets of 100 Eu/kWh are often quoted. The lower limit of the prices may be the raw materials prices. Raw materials cost is normally not considered to be prohibitive to reach lower cost at the moment, but prices from Cu, Li, Ni etc. strongly depend on the economic climate and global demand levels and are outside the influence sphere of the EU. Advanced electrolyte salts have high price levels, but these may reduce upon scaling up the production.

The market of most raw materials is large enough to not feel much influence from a growing EV battery market except for the price of Li. There the impact of increasing Li demand has been reported. When looking to only the Li price and the minimum amount of Li required to produce a ~3V Li cell the target of 75 €/kWh will depend on the actual Li price. Assuming that the cell determines about half the cost of the pack, the cell price level is 37.5 €/kWh. The shear amount of Li in 1kWh must be of the order of 3.6 x 10^6J/3V = = 1.2 MC or 12.5 mol Li, i.e. 87.5 g Li. The price of the 87.5 g Li /kWh would currently be 68.71 x 0.0875 =6 $ up to 105 x 0.0875 = 9.19 €. Here the price of Li per kgis taken from The Economist[1]:price: 13000 $/ton of Li_2CO_3which contains 14 / 73.89 = 0.1895 kg Li. Li price in that equals: 13$/kg/0.1895 = 68.71 $/kg.Another source for the Li price[2] indicates: 150000 CNY = 20265 €/ton for battery grade lithium carbonate. Then the Li price becomes: 20€/kg/0.1895 = 105 €/kg.

Taking the latter as the relevant price level to date, one can state that at 9€ of Li/kWh the Li price would be more than a quarter of the cell price. The price level targets appear challenging therefore. It is further noticed that post-Li-ion technologies such as Na-ion or Li-S may be cheaper than Li-ion, but mass production will not be effective in 2020. Besides, if the pack energy increases, the relative cost of electronic controls, BMS and packaging should decrease.

Political decisions based on safety regulations for transportation may influence the choice of materials and location of production and/or assemblage[3].

COMMENTS ON THE PRIORITIES AS LISTED IN TABLE C) MANUFACTURING TARGETS

Target 1 ***Automotive (Li-ion and next generation post-lithium) battery cell production in the EU***

The 50% statements are not clear. In the target by 2020, 0.25 million of 20 kWh batteries amount to 5 GWh production which is 100% of the target mentioned.

Target 2 ***Utility storage (Li-ion and next generation post-lithium) battery cell production in the EU***

[1] http://www.economist.com/news/business/21688386-amid-surge-demand-rechargeable-batteries-companies-are-scrambling-supplies
[2] http://www.prnewswire.com/news-releases/global-and-china-lithium-carbonate-industry-report-2016-2020-300247531.html
[3] See for instance: http://www.iata.org/whatwedo/cargo/dgr/Pages/lithium-batteries.aspx, http://www.iata.org/whatwedo/cargo/dgr/Documents/lithium-battery-guidance-document-2015-en.pdf, http://www.phmsa.dot.gov/staticfiles/PHMSA/DownloadableFiles/Files/UN_Test_Manual_Lithium_Battery_Requirements.pdf

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a) The volume of manufacturing batteries in general, and batteries related to EV in particular, needs careful consideration. The desired volume in GWh capacity depends strongly on the implementation rate of intermittent renewable electricity sources and market models behind those. The overarching goals of the EU on CO_2 emission reductions are driving the implementation of these electrical renewables. In 2030 the legalised emission goal of the EU is -40% CO_2 in 2030 and -80 to-95% in 2050 for all emissions. So this includes emissions from the electricity sector (~20 – 25% of the total) and the 75-80 % of all other sectors (transport, heating, industry, chemical conversions …). Not only the electricity sector but also the transport, heating and industry sectors aim at renewable energy from sun PV and wind power in order to decarbonise. This will necessarily then mean a large increase in electricity generation and use and simultaneously increase of sun PV and wind energy.From model calculations[4], it appears that one requires large TWh volumes of electricity storage in that case in order to store surplus of electricity for times when there is too little available – if one reaches the goals for the renewables implementation. This volume of storage is vastly greater than what is necessary for EV alone.

b) Utility storage seems much too small compared to what is required upon implementing renewable energies (see remark in target 1). The utility storage would also include stationary storage capacities of batteries next to fast EV charging stations.

Target 3 *Recycling*

a) The environmental guidelines regarding materials have been released. They give attention to important aspects of an environmentally friendly battery design such as energy input for production, metal scarcity and so on. An important finding is that considering current state of the art technology there may happen a scarcity of lithium in the future. Therefore, it is recommended to already start with lithium caption during the battery recycling process. At the moment this is not the case. The investigations for recycling and eco design show that the processes applied today are mostly based on a pyro-metallurgical process, meaning that only transition metals are captured while lithium and other materials are only found in the slag. At the moment there are no economic benefits demanding for a better recycling process.

b) Presently Li is not recycled when the Li-ion batteries are disposed, only more valuable metals such as Ni and Co are (Dewulf et al 2010[5]). Umicore let the recycled Li-compound become an aggregate to concrete (Tytgat 2009[6]). Dewulf et al have shown that for Ni and Co, produced from recycling of the metals, there is a decrease of 51% natural resources need compared to producing virgin metal. They did exergetic life cycle analysis and the recycling methods were pyrometallurgical and hydrometallurgical steps at Umicore. Before the pyrometallurgical process at Umicore the automotive Li batteries are dismantled due to size. They are too big to suit the

[4] As in: http://dx.doi.org/10.1063/1.4874845

[5] Dewulf J., Vand der Vorst G., Denturck K., Van Langenhove H., Ghyoot W., Tytgat J. And Vandeputte K. (2010). *Recycling rechargeable lithium ion batteries: Critical analysis of natural resource savings*. Resources, Conservation and Recycling 54 pp 229-234

[6] Tygat, Jan (2009). Li-ion and NiMH battery recycling at Umicore: Strategic Choices

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pyrometallurgical process. This is e.g. done at Hanau in Germany and e.g the dismantled electronics are sent for electronics recycling where precious metals in the electronics are recycled (Sparn 2013[7]).

There are processes to recycle Li into new material for batteries developed by e.g. Recupyl, Umicore and Chemetall but there is currently no economic incitement to recycle the Li in order to regenerate the battery material. Although economically similar to Li, in the Umicore process fluorine will be removed from the gas stream so as to avoid exhausting it. Life cycle assessment studies have to be extended to the recycling steps in order to maximize environmental benefits by choosing the most appropriated processes.

c) Recycling targets should be more ambitious, especially because the volume increase of battery capacity is taking place in EV applications. Replacement of EV batteries will be done by car dealers which is a professional environment that will be able to collect the batteries. Since the whole car will be recycled the batteries inside will also be recycled.

- ***Battery collection rate***

Battery collection rates should be larger than 60% and 75%.

- Recycling efficiency (by average weight)

In view of the other targets for energy density one may expect that the type of batteries will be containing less heavy metals like Cu, Ni, Mn. The elements to be recycled may still be the Cu, Li, F.

- ***Economy of recycling***

The more expensive elements need to finance the recycling. For the very low price cells this may mainly be Li and a bit of Cu current collector, while F is recycled for environmental reasons.

Target 4 *Second life*

a) In relation to second life of batteries one needs to think of safety, energy efficiency and economic recycling aspects. A degraded battery may score poor on energy efficiency (higher over potentials, more heating) and safety which could make recycling a more attractive option.

b) Several institutions suggest the reuse of end-of-life batteries (second life) as for some purposes these batteries may still be worthwhile. Nevertheless, certain critical aspects are concerned with this reuse, such as:
   - Reuse delays return of material for recycling and increases peak demand for virginmaterial (e.g. Nissan will reuse batteries to store energy from PV panels or to store back-up power).
   - Legal issues are still not solved, meaning who will be responsible for the second-life battery.

[7]Sparn Klaus (2013). Technical contact at Umicore, Hanau, Personal communication Feb 29 2013

c) Hence, according to this target, packs need to be dismantled, and cells will be recovered, tested separately and reassembled in new packs designed for targeted applications which will depend on cell chemistry.

Proposed target in Table c) Manufacturing targets regardingEco-design

With regard to the eco-design, there are two major items to focus on:

1. Energy savings

Energy consumption is an important issue and is mainly related to the processes involved, and the environment under which they are carried out; particularly when moisture free environments are required. Often production areas have a DEW point of either -20 or -40, requiring an enormous amount of energy to establish.

2. Solvent reduction combined with hazard prevention (Volatile Organic Compounds (VOCs) etc.)

An eco-friendly feature of the electrode coating method is the minimisation of required solvent and the reduction of the exposure level to nearly zero without requiring expensive protection equipment. In this regard, a potential eco-design process is the production of the Si-based electrode, as this can be processed under a much less controlled environment compared to the current electrodes based on carbons. The solvent here is basically water, so the use of VOCs here is very limited, if any. This reduces the energy consumption usually required for maintaining a moisture free atmosphere during the electrode processing.

Recommendations on prioritising Research &Innovation activities

a. In general the battery field is a very active area of research worldwide. When the EU has the ambition to become competitive in the global battery sector there should be priority for educating workers and researchers in this area. These workers and researchers then can help growing and shaping the future of the EU battery sector. The presence of skilled workers and researchers is also a condition for foreign industries to come to the EU.

b. The solutions for the batteries that reach the targets as discussed are not yet available. In order to educate workers and researchers there needs to be at university level research in advanced types of battery systems for EV, and also in static batteries that can be applied near fast charge stations. The latter batteries will be similar and scalable to general utility types of storage.

c. Industry needs projects in which scale-up and long term testing of the required novel technologies can be performed. During scale up and long term testing new questions will arise on which research is to be performed in collaboration with universities and institutes. By having such links between industry, institutes, and universities there then occur training and research opportunities to educate workers and researchers in the field of batteries for EV. The successful scale up projects will lead to start-up of battery businesses and will provide education opportunities for skilled workers and researchers.

d. In regions where EV is already rolled out, and/or where renewable energy is implemented at significant scale of renewable electricity supply, business cases for battery storage will be more profitable. This battery storage may first involve implementation of smart EV charging solutions, using renewable electricity peaks, and it may involve a fast charge stationary battery network that will play a role in stabilising the grid and alleviate grid costs.

e. Introduction of EV on a large scale is one of the ways to reduce CO2 emissions. The same is necessary for all other energy consuming sectors. This will, however, lead to increased electricity use 24h/365d of the year. There is a need to evaluate existing ENTSO-E Vision 1-4 scenarios of the EU electricity transport grid providers. In the scenarios, there is only a small increase of electricity use in the same timeframe that there are strict CO_2 reduction targets for all energy consuming sectors.

f. Improving the understanding of the mechanisms in Li-ion batteries, and focus on materials, processing and chemistries that have a commercial potential. This includes also for example processing and binders for environmentally friendly manufacturing.

g. Fundamental research should also include to a larger extent than today the construction materials on cell and pack level, electric connectors etc.

h. Competence necessary for advanced BMS is also extremely important.

i. Recycling must be emphasised, and implications of recycling ambitions should be included down to cell chemistries.

j. If charging stations are within the scope, it will require development of low cost high power devices (this might be already part of stationary storage programs).

k. To identify the potential impacts of the growing market for automotive lithium-ion batteries, research could be devoted to:
   - Conducting studies to identify the greenest, most economical recycling processes,
   - Investigating recycling practices to determine how much of which materials could be recovered with current or improved methods, and
   - Quantifying the environmental impacts of both battery production and recycling processes through life-cycle analyses using Argonne's GREET model[8].
   - Researchers leverage Argonne's BatPaC model[9] to determine the material compositions needed to perform LCAs on different Li-ion battery chemistries.

The information has been gathered in "Fact Sheets" such as:

- Closing the Lithium-ion Battery Life Cycle (fact sheet; January 2014)
- Energy and Materials Issues That Affect Electric Vehicle Batteries (fact sheet; May 2013)
- How Green is Battery Recycling (fact sheet; October 26, 2012)
- LCA: https://greet.es.anl.gov/greet/index.htm

For all those three items – costs, Life-Cycle Assessment (LCA), and Eco-design& recycling – the production process plays a major role. Since the items are so interrelated, it is clear that recycling helps economics. In that regard, it is a start that in Europe, a 50% of cell materials must be recycled as of ~2020, followed by more than 50% of cell materials should be recycled as of ~2030. This then should include enough valuable materials to make recycling paying offeven if low valuable materials such as $LiFePO_4$ cathodes are used. It is further stressed thatthe responsibility for EU recycling belongs to the company that makes the consumer product. Recycling, therefore can also drastically reduce virgin lithium demand, considering those parts of the production to be ready for recycling.

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[8] https://greet.es.anl.gov/
[9] http://www.cse.anl.gov/batpac/