Energy Storage

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Regulations relevant to the cruiser class

- 2.5.1 A solar car may store energy. A standard energy storage system uses rechargeable electrochemical cells. Teams wanting to use some other form of energy storage must send details of the proposed energy storage system to the event organiser for approval.
- 2.5.7 The energy storage system must be contained within at most two packs
- 2.5.8 Electrochemical cells must not, at any time, be operated outside of the operating ranges for voltage, current and temperature specified by the manufacturer. Teams must provide manufacturer's specifications that include:
  - minimum operating cell voltage
  - maximum operating cell voltage
  - maximum discharge current
  - maximum charge current
  - maximum temperature while discharging
  - minimum temperature while charging
  - maximum temperature while charging
- 2.5.9 Teams must provide documentation that describes how they will monitor their electrochemical cells, and what the team and the solar car will do if any cell goes outside specified operating limits. Teams must obtain endorsement by their certifying engineer that an adequate and effective monitoring regime has been designed and implemented, and fault conditions will be managed safely
- 2.5.10 Batteries are not considered to be part of the energy storage system, provided that the total energy capacity does not exceed 2.0 Wh.
- 2.5.11 Batteries or cells inside devices such as handheld radios, cameras, mobile telephones or wristwatches that are carried by the driver or passengers are not considered to be part of the energy storage system, provided that they are not electrically connected to the solar car, its instrumentation or control systems.
- 2.5.13 Energy storage packs must be mounted in the solar car so that they will be restrained in a 20g acceleration.
- 2.5.14 If an energy storage pack is capable of spilling dangerous liquids when damaged then there must be a spill-proof barrier between that energy storage pack and the solar car occupants.
- 2.5.15 If an energy storage pack is capable of emitting dangerous gases when damaged then the solar car must be designed so that any gases from a damaged pack will be vented to the exterior of the solar car behind any occupant ventilation intake.
- 2.5.16 Removable energy storage packs enable teams to work on their solar car while their energy storage packs are impounded. If energy storage packs are removable then:
  - each energy storage pack must remain in safe state while not connected to the solar car
  - each energy storage pack must meet the electrical safety requirements of Section 2.28 while outside of the solar car

  - the team must provide a lockable box for storing energy storage packs while they are impounded.

- 2.5.17 Energy storage packs must be constructed so that each pack can be sealed using tamper-evident plastic seals, similar to 3 × 100 mm plastic cable ties. With seals fitted, it must not be possible to remove any cell from a pack without breaking the seal. Seals will be provided by, and fitted by, the event organiser at scrutineering.
- 2.5.18 Energy storage packs must be designed and constructed so that scrutineers can verify the cell models being used and the number of cells of each model.
- 2.5.19 Any charging system that is used to recharge the energy storage system (when allowed) must meet the following requirements:
  - the charger must be used with a residual current device
  - the charger must be either permanently connected to the energy storage system, or connect to the energy storage system using an appropriate connector
  - the output of the charger must be electrically isolated from any ac input
  - the charger must stop charging automatically when the energy storage system is full or if a fault occurs.
- 2.5.20 Cruiser charging will be metered by the organiser. Cruiser solar cars must be equipped with an on-board ac charger with an IEC 62196-2 Type 2 (male) charging inlet and be capable of charging from a single-phase ac supply (230 Vac, +10%, -6%). The ac current draw must not exceed the limit indicated by the SAE J1772 pilot signal generated by the organiser's Electric Vehicle Supply Equipment (EVSE), which will allow charging rates up to 30 A but may reduce the limit to as low as 6 A. The EVSE may disconnect the car if the indicated current limit is exceeded for more than 5 seconds.

Battery Pack

The battery module should probably be build by us, since we most likely need quite a bit of customization. It is also hard to find packs for sale as well as most for sale are repurposed, which is bad for reliabillity and safety. From YouTube videos it does not look super difficult to built such module, the biggest problem would be special tools for the process (these are could be available at DTU). However, all the monitoring- and management systems can easily be bought.
A widely used electrochemical cell chemistry in EV power-trains is Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2) — NMC. It has high specific energy: 150-220 Wh/kg. It is safer than similar chemistry (LCO & NCA) beacuse of low self-heating rate. However it comes at a price about $430 per kWh.[1] Lithium-Sulfur (Li-S) chemistry is not an option because we would have to make it on our own. since "To date, there are no commercial Li-S batteries in the market."[How Far Away Are Lithium-Sulfur Batteries From Commercialization?][2]
Looking at a solution similar to the Sunswift eVe solar vehicle, which has a 16 kWh battery composed of 1326 Li-ion cells (Most likely Panasonic NCR18650B 3350mAh - 6.7A (NMC)) configured as a 39 series × 34 parallel (39s34p) pack. The gives a capacity of 113 Ah and a voltage range of 113.1 - 163.8 V. The cells alone weighs about 63 kg and measures about 702mm × 612mm × 65mm. The cost of all the cells alone is about 4309 EUR (33.000 DKK)[3]. Additional parts (Spacers, Nickel tape, Wires, fuses, breakers, etc.) are estimated to be about 5000 DKK combined.
Additionally the battery module should be in an enclosure (pack), as it needs to be mounted so that it can sustain a 20g acceleration.

[1] https://batteryuniversity.com/learn/article/types_of_lithium_ion
[2] https://www.frontiersin.org/articles/10.3389/fenrg.2019.00123/full JOURNAL: Frontiers in Energy Research November 2019
[3] https://eu.nkon.nl/panasonic-ncr18650b-made-in-japan.html

Battery Management System

Possible supplier LiTHIUM BALANCE A/S. Was a start-up at DTU and is now located in 20 km west of DTU in Smørum. They have BMS that are advanced and does a lot of monitoring, which helps with safety. Furthermore the BMS have been tested to be very robust and reliable. At the moment they dont show any prices. Smaller and but still advanced BMS (comes with built in connection and monitoring applications) comes at a prices off roughly 160 EUR [4]

Charger

Chargers are very expensive, cost more than $500. Furthermore the car needs to be fitted with a certain inlet. See regulation 2.5.20. A talk with some of the people from PowerLabDK, building 329

[4] https://www.energusps.com/shop/product/tiny-bms-s516-150a-750a-36?category=4