Eco-Sustainability of Power Systems Concepts

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Battery powered technology and vehicles are more eco-sustainable than using fuel, but also have their own drawbacks. The disposal of batteries causes harm to the environment due to both the processes and the lack of disposal units (meaning transporting the batteries). Strathloop's battery system is eco-sustainable, but needs improvement, using Lithium Ion batteries was decided to still be best suited for the pod. The main ways in which this can be achieved are by renewable energies and second use batteries.

I. INTRODUCTION

One of the main advantages of Hyperloop is that it is a new eco-sustainable mode of transport. Therefore, this project is about making the power systems for Strathloop's pod as eco-sustainable as possible. This involved researching environmentally friendly energy ideas, investigating how ecologically sustainable our power system is currently and trying to make the power systems more eco-sustainable where possible. The results have been achieved by week to week individual tasks set by the Power Systems sub-team, and the research and comparison of the ideas brought forward.

II. METHOD/ANALYSIS(RESEARCH)

A. Current Strathloop Power Systems

The system is powered by lithium ion batteries and uses Lithium Nickel Cobalt Aluminium Oxide cell type (NCA). These are the batteries currently used by Tesla [7]. The power distribution method uses a daisy chain Battery Management System (BMS) architecture, this is an electronic system that ensures the batteries operate at the correct conditions and can also calculate secondary data. The daisy chain model consists of the cells connected in series; the series chains are then connected in parallel until the voltage and capacity is of the correct amount. The physical battery pack is a two-pack design which consists of one pack with 4 series and 2 parallel, and the other with 3 series and 2 parallel. They provide 14.4 V/6.4Ah and 10.8V/ 6.4Ah respectively. The system powers the actual pod's power systems by using a phase invertor circuit. This is needed to convert the DC battery power to AC in order to power the different three phase motors on the pod. The circuit uses the Pulse width modulations on an Arduino board (microcontroller). The power system can be said to be eco-friendly to an extent, however there could be some improvement. The BMS and phase invertor circuits are eco-friendly due to being relatively low powered. The lithium ion batteries come with environmental drawbacks when it comes to their disposal [1].

Since the battery used in the systems was Lithium Ion, the pros and cons of this battery were evaluated. The pros of Lithium Ion batteries are; a high cell voltage means that many applications only require one cell; reducing waste and saving space; the battery does not require much maintenance i.e. no periodic discharge is required; the batteries have a large cycle lifetime compared to other batteries (2000 charge/discharge cycles for a standard Lithium Ion battery compared to typical lead acid batteries which normally last only 500-1000 cycles); the batteries are not damaged if not fully charged regularly and they are efficient at storing energy.

The cons of Lithium Ion batteries are: the protection circuit limits the peak voltage of each cell during charge and prevents the cell voltage from dropping too low on discharge; capacity deterioration is noticeable after one year; whether the battery is in use or not (he battery frequently fails after two or three years although; some have been known to last 5 years in certain application); they need to be stored at around 15 degrees Celsius while fully-charged, and can be recycled, but only at permitted treatment facilities. When discarded, they must be disposed of at a household e-waste collection point or battery-recycling drop off location.

B. Other Batteries

One other battery type researched was Sodium Sulphur. The positives of this battery includes: lifetime of about 4500 cycles; the rated power output is 50 kW and 400 kWh and efficiency is around 85% [2]; Sodium Sulphur batteries have one of the fastest response times; the maximum charge voltage is 1.55 kV; the maximum discharge voltage is 930 V; the net efficiency is 89.1%; the system standby efficiency is 96.1% and the energy density is 150-240 Wh/Kg. One negative is that temperatures over 350 degrees Celsius will decrease the energy efficiency and may cause corrosion in the system. These batteries are considered eco-friendly because sodium and sulphur are highly abundant in nature.

Another battery researched was the Hydrogen Fuel Cell. Some positives about Hydrogen Fuel Cells are as fol-

lows: when it comes to rechargeability; fuel cells have a quick fill-up time of minutes as opposed to the hours-long charging time that batteries need; hydrogen fuel cells are between 40-60% efficient [3], which is higher than a typical combustion engine of a car that is typically only 25% efficient (fuel cells can also be altered to combine heat and power that increases the theoretical efficiency to 80-90%); a fuel cell system running on hydrogen can be compact and lightweight and do not involve combustion; in ideal conditions they can achieve up to 99.9999% reliability; the theoretical voltage for a hydrogen fuel cell should be 1.23 V, 120 MJ/kg, i.e. 33.6 kWh, almost three times more than diesel or gasoline. Graph representations of battery comparisons were created.
Figure 1 shows the comparison of the three researched batteries showing their power efficiency. From this graph it is clear to see that Sodium Sulphur has the most power efficiency while Hydrogen Fuel Cells had the least.

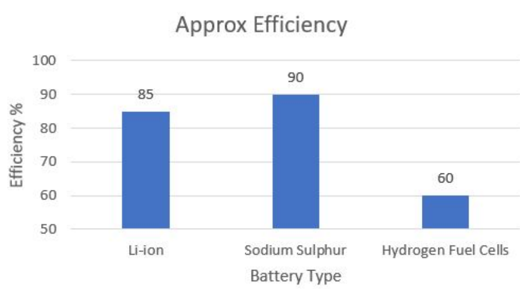

FIG. 1. Power Efficiency of Batteries[2,3,4]

Figure 2 shows the power-to-weight ratios of the three batteries. From this graph it is clear to see that Hydrogen Fuel Cells have the best power-to-weight ratio, whereas Sodium Sulphur has the worst.

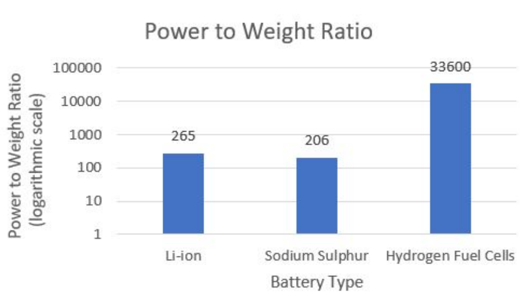

FIG. 2. Power to Weight Ratio of Batteries[3,5,6]

Figure 3 shows the environmental comparison of the three batteries. It can be seen that Sodium Sulphur is the best battery environmentally, whereas Lithium Ion is the least suitable environmentally.

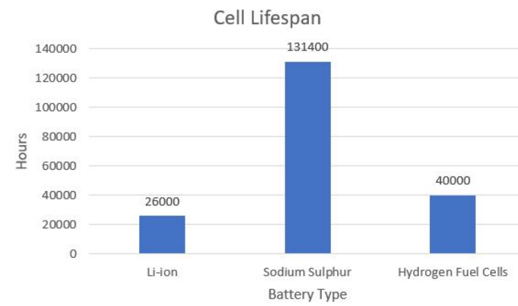

FIG. 3. Cell Lifespan of Batteries [3,5,6]

C. Environmental Aspect

Tesla battery packs consist of Li-ion cells. They use this battery system to allow for the best possible acceleration and range with their vehicles. Tesla views these batteries as the best available on the market currently [7]. Another reason for using them is not just the power output, but also they have a good cycle life (number of full charges it takes for the cells capacity to reduce by a fraction). Although these batteries work like how they would in a laptop or mobile phone, Tesla cars use their batteries like how the pod would need to use it. Batteries used in the mobile phone and laptop industry were Nickel Cadmium batteries. The main disadvantage with these were they suffered quick capacity degradation. This problem does not occur with Li-ion batteries. A study shows that over 30,000 miles the Tesla battery pack only degraded 5%. Tesla battery packs take between 20 and 40 minutes to charge, but this is to prevent degradation due to the charging limits [8].
As part of this research, the team investigated renewable energies to see if this could be an option for the pod. Types of renewable energy researched were: solar panels to harness the sun's energy to produce electricity; wind turbines, wind turns the blades of the wind turbine in which turn rotating the coils within the turbine to make electricity; hydro, a similar method to wind using fast-flowing water (from a dam, water chutes etc) to move the turbine in order to produce electricity; tidal, another form of hydro energy using the twice-daily tides to produce electricity; geothermal, which uses the earth's natural heat to heat homes or generate electricity directly (essentially useless in places like the U.K.); and biomass, which is burning organic waste to make electricity [9]. The knowledge of these renewable energies was then used to see which could be used on the pod. Currently, many cars use biomass fuel as an alternative to petrol to reduce the volume of CO_2 gas produced [9]. Trains use very similar tech to Hyperloop-electric trains use batteries and are moving towards solar energy within the last year. For the pod we would need a storage device to contain the energy produced through

solar to utilise it on our pod, especially before going into a tunnel. Also, if our pod was being used in a volcanic environment, i.e. in Iceland, biomass could be used. This isn't as useful in the U.K. Finally, wind is also a very containable and transportable form of renewable energy and it could be used on the pod [10].
Another eco-sustainable concept that was researched was second use batteries. There are car companies across the world who already use second use batteries. Second use batteries only lose around 20% of capacity before being replaced, so the remaining 80% is to be used for storage. Also, this is a way to bring down the capital costs of commercial and grid scale battery installations, meaning more companies could be inclined to use batteries in cars, and because of the profitable second life that can be used as backup storage for grid scale solar photovoltaic installations. Overall, this would save greenhouse gas emissions by reusing materials instead of mining for more [11].
One electrical storage device that would make second use batteries more worthwhile is the supercapacitor. These are fully-renewable, making them environmentally friendly. They can replace fuels for transport such as gas, and therefore reduce CO_2 emissions [12]. Hybrid supercapacitors have been developed to combine the supercapacitors energy intake with the battery's long-term storage abilities [13]. Although they are cost efficient, they are still quite expensive.
A much more eco-sustainable battery system could possibly be Hydrogen Fuel Cells paired with super capacitors, however this is an expensive option which would most likely be outwith a competition pods budget [13].

D. Disposal of Batteries

One of the main reasons why batteries are not fully eco-sustainable is because of how they are disposed.
The following steps must be taken for Lithium Ion batteries to be disposed of correctly. Household Lithium Ion batteries must be disposed of at household e-waste collection point or battery-recycling drop off location. It must be ensured that the batteries are not exposed to high temperatures, prolonged sunlight, water or humidity. Handling the batteries must be done carefully to ensure that the casing is not damaged and ensure that the cores do not come into direct contact with each other and are completely discharged. There are two main ways to dispose of these batteries: hydrometallurgical and pyrometallurgical [14].
The hydrometallurgical process recycles 80% of lithium-ion materials [15], although when leaching, chorine is generated that may result in serious environmental problems. There is a large consumption of chemical reagents. Organic acids can be used to make this process more environmentally friendly [16]. When combined with physical processes, all components can be recovered.
The pyrometallurgical process uses high temperatures, high energy and has a high metal loss rate [17]. All battery chemistries can be recycled simultaneously. There is a gas clean up required to avoid toxic air emissions [18].
Comparing these processes, neither is good for the environment. While hydrometallurgical has the potential to release chlorine during leaching, which is damaging to the environment, pyrometallurgical required a high amount of energy, as well as gas clean up. Hydrometallurgical chlorine emissions can be reduced using chlorine gas. Though pyrometallurgical has a high metal recovery rate, it also has a high metal loss rate during the extraction process, which is not ideal for optimal recovery of parts. The hydrometallurgical process can recover much more of the components, making it more efficient. As hydrometallurgical is more efficient in the recovery of battery parts and the impact on the environment can be reduced, this will be recommended for use.
For batteries to be disposed of correctly, they must go to a disposal unit [19]. There are currently no Lithium Ion battery disposal units in the U.K. The U.K. only recycles certain battery types; however it does have a sorting facility for batteries. The closest disposal unit for the U.K. is Umicore in Hoboken, Belgium. Lithium batteries were supposedly the cause of an air crash in Dubai in 2010. For this reason, there are tight regulations over their transportation, unless they are already in the products they power. Consignments of the batteries themselves are banned from U.K. aircraft. Belgium can recycle up to 7,000 tonnes/year of lithium batteries to extract Lithium, Cobalt, Nickel, Copper and rare-earth elements. Umicore has agreed to work with Audi towards closed-loop recycling in electric vehicles (EVs). Audi has demonstrated in lab tests that 95% of battery metals are recoverable from its EV batteries. Most of the batteries that do get recycled undergo a high-temperature melting-and-extraction, or smelting, process similar to ones used in the mining industry. The plants are also costly to build and operate and require sophisticated equipment to treat harmful emissions generated by the smelting process and do not recover all valuable battery materials. Hydrometallurgy processing, or chemical leaching, which is practiced commercially in China, for example, offers a less energy-intensive alternative and lower capital costs. This shows that even if all batteries are disposed of correctly at the closest disposal unit to the U.K. there are more environmentally friendly ways [20].

E. Other Factors

It is known that Lithium Ion batteries are not always cheap. It is clear to see though that the cost of these batteries is improving over the years. According to Bloomberg New Energy Finance, the average global cost for lithium-ion batteries in 2018 was about $175 per kWh, compared to nearly $1,200 per kWh in 2010 [21]. It is expected that the price of an average battery pack to be around $94/kWh by 2024 and $62/kWh by 2030 [22]. Depending on the power supply that is required, purchasing a fresh lithium ion battery may be necessary. It looks like a second use battery should be more than capable to be used as the battery storage for the project as overall costs are lower and the batteries should be able to supply the demand that is needed. Another factor is the charging time of the battery. The charging time of Li batteries is dependent on the power a charger can provide [23]. Tesla v3 superchargers are currently the fastest chargers available for EVs, theses provide 250kW which can fully charge an EV in around 15 to 40 minutes. This translates to giving an EV a range of 1000 miles in 1 hour of charging [24]. Lithium ion batteries are very susceptible to overcharging. This however is easily avoided by using a smart charger that can be set to charge the battery to a desired level [24]. Supercharging Lithium Ion batteries does lead to a premature death of the battery if it is used often. Therefore, Tesla currently advises supercharging only for long distance travel and advises that their EVs be charged more regular form low kW charges such as ones installed in homes. Another strategy Tesla has employed to avoid premature battery aging is by reducing the supercharger kW charge rate depending on how many miles an EV has done [24]. This means that using a supercharger such as a Tesla V3 to charge the batteries on the Hyperloop is a fast way of charging the pod, however will potentially lead to premature battery aging. Because second use batteries will already have done many charge and discharge cycles, using a supercharger on them may mean they do not last a long enough time to be viable [25].

III. RESULTS

The main decision for the team was to decide which battery is best for our pod and if it was worthwhile to consider second use batteries. Looking at Table 1, Lithium Ion was voted as the best for the pod. It was also voted that second use batteries would be useful, with the two people voting "depends on" meaning that it depends on the cost of Lithium Ion batteries. This means it must be researched if the damage to second use batteries (having only 80% capacity) is worthwhile for the pod. The value of a second use battery for a competition pod would depend on where the battery came from, and the quality of the battery.

Voting for Batteries	
Battery Type	
Lithium Ion	7
Sodium Sulphur	0
Hydrogen Fuel Cell	0
Second use Batteries	
Yes	5
No	0
Depends on Li Ion cost	2

FIG. 4. Results from Battery Votes

In order to improve the eco-sustainability of the overall pod and Hyperloop, it was decided that renewable energies could be a positive direction. A potential way to improve the eco-sustainability of the Hyperloop is to incorporate solar panels into the loop. This project would depend on the actual specifications of the Hyperloop, e.g. if it is above ground or if it is located in an area of adequate sunshine. Provided that the environment is suitable for the incorporation of solar panels on the track, the pod could be charged from an environmentally sustainable source. If such an idea was employed, it would have to be ensured that either there would be enough storage potential with enough tolerance so that the pod could continue to run outside daylight hours and also during sustained time periods of cloud cover. Other sources of renewable energy could be used to generate power for the pods. To optimize power generation, this may mean that the renewable energy source may not be located that close to the Hyperloop and it would therefore likely be powered from a national grid where the power comes from a number of different sources, renewable and non-renewable. If enough renewable energy was produced, it would allow the project's carbon footprint to be zero or potential negative.

One other improvement could be moving from the pyrometallurgical process of disposal to the hydrometallurgical process. Hydrometallurgical recycling process would allow 80% of the material in a lithium-ion battery to be recovered. Although the hydrometallurgical process is not entirely environmentally friendly, due to the release of chlorine gas, recycling Lithium ion batteries using this method would mean that less mining would need to be conducted to gather the necessary materials. This would likely mean that less environmental damage is created elsewhere from mining, reducing the carbon footprint of Lithium ion battery production

IV. CONCLUSION

While battery powered systems are more eco-sustainable than using fuel, there are many ways in which things can be improved. Disposal of batteries is one of the biggest issues, starting with the fact there are no Lithium Ion battery disposal units in the U.K. The process in which batteries are disposed also have much room for improvement.

Eco-sustainability is all about preserving nature to not harm generations in the future's lives. With respect to power systems, this can be interpreted through using green products, powering the pod using renewable energy and recycling the battery system when it can no longer be used.
Simple, effective ways that the power system can be more eco-sustainable would be through using a second use lithium ion battery and using renewable energy to recharge the battery. In Scotland, the most abundant and effective source of renewable energy is onshore wind. Then, when the battery cannot be used further, it would have to be sent to the lithium ion battery recycling centre in Belgium. This would eliminate waste produced and reduce CO_2 released to the atmosphere.

V. ACKNOWLEDGEMENTS

The author would like to thank the whole Strathloop team, particularly the Power Systems sub-team for the ongoing help with this project and report.The sub-team would like to acknowledge the University of Strathclyde for their resources and time, the Hard Tech Fund for giving us the opportunity to present our work, and our sponsors Bitzlist and monday.com.

Author Contributions: K.M. drafted and edited the paper alongside research with the power systems sub-team.

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