BATTERY BOX BESS

Life Cycle Assessment: Battery Energy Storage System

AMP Clean Energy

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1 EXECUTIVE SUMMARY

This report details the Life Cycle Assessment (LCA) for the AMP Clean Energy battery energy storage system (BESS), also known as a battery box, that is to be built at Colchester, Essex, UK. The LCA has been conducted in line with the ISO 14040 and ISO 14067 standards.

The LCA covers the construction of the site (including extraction and refining of raw materials, energy use during the manufacture of batteries and other equipment), its operation for the lifetime of 2 sets of the battery cells (assumed to be 7,118 cycles until performance drops to 67% of the original capacity), the recycling of the battery cells and the decommissioning of the site (with potential recovery and recycling of materials). AMP Clean Energy have provided the available details for the LCA, such as product specifications, manufacturing locations, details of manufacturing processes, construction activities etc. In the absence of supplied information, the LCA is based on data obtained from publicly available reports, product specifications and other resources and where these have not been provided the relevant information assumptions have been made in agreement with AMP Clean Energy. Throughout the LCA, the sources of data are referenced, or where estimates or assumptions are made this is explicitly stated.

1.1 Conclusions

The overall result of the LCA is that the carbon emissions associated with the lifecycle of the BESS equate to 0.062 kgCO2e/kWh of energy generated by the batteries and provided to the National Grid. This figure is based on the estimated average carbon intensity for the electricity used to charge the batteries over the 15 years of their lifetime and then the subsequent 15 years for a replacement set of cells, taking into account the variation of carbon intensity at different times and the planned decarbonisation of electricity generation over the coming years. It also takes account of material recovery at the end of the life of the battery cells and other equipment and materials onsite. The recycling of batteries means batteries can be produced in the future that do not require so many raw materials to be extracted and processed (e.g. through the recycling of the battery cells). Other materials used can also be recycled and in total, material recovery could prevent up to 76,655 kgCO_2e of emissions, although the recycling processes themselves would emit 27,408 kgCO_2e (including transport to waste disposal and recycling sites from the Project site). As electricity generation in the UK and the processes involved with creating batteries and other equipment are gradually decarbonised and fossil fuels like natural gas are phased out, the environmental benefits of the BESS, in terms of carbon emissions against power generation sources feeding into the National Grid, will decrease over time. However, battery storage is still an important part of the energy transition in terms of managing the difference in supply and demand when using renewable energy sources such as wind and solar power.

The 0.062 kgCO2e/kWh figure compares favourably with the current figure of 0.430 kgCO2e/kWh for electricity generated by natural gas-powered power stations (CCGT, combined-cycle gas turbine), meaning that if the use of the BESS can prevent the use of fossil fuels to generate electricity, then it will be environmentally beneficial. This figure also compares favourably with the emissions associated with flexible open cycle gas plants (gas peakers), which are 0.651 kg CO_2e/kWh. Based on the total output of power to the grid from the small BESS over 30 years, it can save 99 tonnes of CO_2e per year on average, when compared with natural gas power stations, and 159 tonnes of CO_2e per year compared with the use of gas peakers.

The emissions calculated are dependent on the carbon intensity of the electricity from the National Grid used to charge the batteries, which is variable and at times will be hard to predict. Excluding the carbon emissions from charging the batteries results in a figure of 0.017 kgCO_2e/kWh for the energy generated, and the overall figure can be calculated by adding this to the carbon intensity of the electricity used to charge the batteries.

Recommendations:

- Operational emissions are by far the largest area of carbon intensity and when operational data is available this should be used to update the LCA and improve its accuracy.

- Review the areas of most significant emissions and consider how emissions can be minimised for this and future projects.
- If any other data becomes available that would improve the accuracy of the LCA, either before or during the operation of the Project, this should be included in an updated LCA (unless any differences are negligible).
- Developments with LFP battery recycling should be monitored so that at the end of the life of the cells the most suitable disposal route can be determined. The LCA can also be updated to reflect developments with recycling, as they can have a major impact in the overall LCA reduction.

2 GLOSSARY

BESS	Battery energy storage system
BMS	Battery management system
CCGT	Combined-cycle gas turbine
DNO	Distribution Network Operator
GWP	Global warming potential
HVAC	Heating, ventilation and air conditioning
ICE	Inventory of Carbon and Energy
$kgCO_2e$	Kilogrammes of carbon dioxide equivalent
kWh	Kilowatt hours
LCA	Life cycle assessment
LCI	Life cycle inventory
LFP	Lithium iron phosphate ($LiFePO_4$)
NMC	Lithium-nickel-manganese-cobalt oxide
O&M	Operations & maintenance
PCS	Power conversion system
SCADA	Supervisory control and data acquisition
T&D	Transmission & distribution
UK	United Kingdom
UPS	Uninterruptible power supply

3 INTRODUCTION

AMP Clean Energy has commissioned DNV to undertake an LCA of an 838 kWh small BESS at Colchester, Essex, UK, (the "Project"). The Project is AMP Clean Energy's first of this kind, with many more planned. The LCA has been conducted in line with ISO 14040 requirements [1] and considers the various inputs into, and outputs from, the procurement, construction, operation and decommissioning of the Project, as summarised in Figure 1 below.

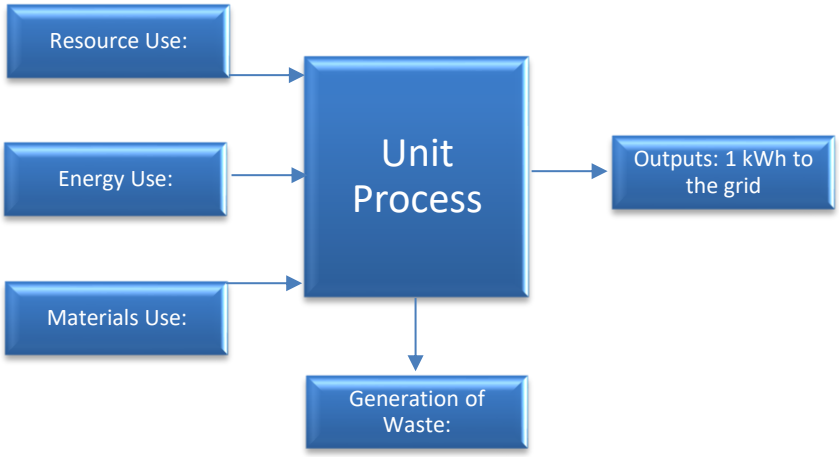


Figure 1: LCA Methodology

The functional unit is the quantity of CO_2e (in kg) emitted for each kWh of electricity output provided by the BESS to the electricity grid, in $kgCO_2e/kWh$.

ISO 14067 [2] has also been followed in order to define the carbon footprint of the Project.

This LCA report details the following:

- The scope of the assessment, which defines what is included and what is not included in the calculations and the overall goal of the LCA
- The life cycle inventory, which identifies the relevant inputs and outputs to be included (as shown above)
- The life cycle inventory analysis (LCIA), the process to calculate and quantify the environmental impact of each part of the inventory in terms of equivalent CO_2 emissions (CO_2e)
- The interpretation of the results

The data presented within this report has either been provided by AMP Clean Energy or has been found from the latest available sources at the time of writing (see references provided). Where the required data has not been made available, assumptions have been made based on knowledge in agreement with the Customer. Where assumptions have been made, these have been stated.

It is recommended that the LCA be kept under review and updated to include more accurate data if and when it becomes available, e.g. from the supply chain or data from the Project once it is operational.

4 LCA SCOPE

AMP Clean Energy has requested a 'cradle to grave' LCA focussing on the carbon emissions associated with the Project. Therefore, the scope covers three broad areas and the CO_2e emissions and other environmental impacts associated with them:

- Construction: i.e. building of the Project, including manufacture and transport of the equipment/materials within it and used to create it;
- Operation: i.e. the running of the Project, based on a lifespan of 30 years; and
- Decommissioning: i.e. the recycling of the battery cells, demolition of the Project and recycling of any recovered materials.

The geographical boundary of the study is the Project site in Colchester, Essex, UK, with matters relating to the construction, operation and decommissioning of the Project (e.g. the recycling of the battery cells) within the Project boundary considered. The Colchester site is the first of many of these small BESS projects being constructed by AMP Clean Energy and while the calculations in this LCA use the Colchester site, e.g., for calculating transport emissions, the aim is for the LCA to represent a 'typical' small BESS site where the same equipment is used.

For each stage the CO_2e emissions will be estimated, while other environmental impacts, such as the generation of hazardous and other wastes, will be identified. The CO_2e emissions will be estimated in line with ISO 14067 requirements. One functional unit has been defined, this being the quantity of CO_2e (in kg) emitted for each kWh of electricity provided by the BESS to the electricity grid, given in $kgCO_2e/kWh$.

The data to be used for the LCI (life cycle inventory) will either be Project-specific and provided by the Customer, their contractors and/or suppliers, or taken from reliable sources, which will be referenced. The LCI is all of the data collated for the LCA, including the number and type of battery cells and other items of equipment, the carbon intensity of the constituent materials and everything else which is then used to produce the LCA. Preference will be given to Project-specific data. When using other data sources, preference will be given to the most recent data from bodies such as governments, regulatory bodies and other peer-reviewed and reputable studies. Where assumptions are made in the absence of data, these will be stated.

For the CO_2e emissions, data will be sourced for the embodied carbon of materials and equipment needed for the Project, the emissions associated with transport of the materials and equipment to the Project site and emissions from energy use (i.e. energy from the grid and from fuels used onsite, fuel used for transport is considered in the transport emissions). This applies to the construction, operation and decommissioning stages. All data used for the calculations will be stated. Any other sources of emissions, such as transport of construction staff to the Project, have been deemed to be either irrelevant or insignificant and have been excluded from the calculations. Some calculations will be done based on current emissions data, that over time will change. For example, electricity used from the grid during the operational stage will have lower CO_2e emissions at the end of this stage than at the beginning due to the planned decarbonisation of electricity generated in the UK. As the future emissions are not known, projected figures will be used. For the decommissioning stage, the calculations will be done based on current data in the absence of projected data that would apply to this stage after 30 years of operation.

Emissions from electricity from the grid will include emissions from generation and the transmission and distribution of the electricity.

It has been assumed that the transport of materials and equipment to the Project site will take place by ship and/or by road, with no requirement for any material or equipment to be transported by air.

Where assumptions have been made, these have been stated explicitly in the following sections. Extracts of the LCA calculations are shown in Appendix A and show the breakdowns of constituent components for equipment, travel distances, power consumption and the other calculations summarised in the sections below.

It should be noted that LCAs such as this do not provide an exact description of the environmental impacts and the carbon emissions calculated are an estimate based on available data, rather than an exact figure.

Regarding the CO_2e emissions calculated in the LCA and used for the CFP (carbon footprint of a product) study, the carbon emissions from the plant will be calculated, as will the benefits of the recycling of materials at the end of the Project's lifetime.

5 CFP STUDY GOAL

As per ISO 14067 the overall goal of a CFP study is "to calculate the potential contribution of a product to global warming expressed as CO_2e by quantifying all significant greenhouse gas (GHG) emissions and removals over the product's life cycle or selected processes". In this case the entire life cycle will be used.

The primary intended application of the CFP study is for the Customer to use internally to measure its environmental impact. It will also be used as evidence for the environmental benefits of the Project.

The reasons for carrying out the CFP study are to have a qualitative and quantitative, independent third-party view to indicate the environmental impacts and benefits of the Project in terms of the associated greenhouse gas emissions.

The intended communication is for the key findings of the report to be able to be publicised widely if the Customer wishes to do so, with the full version of the study shared with select individuals and organisations on an as-needed basis.

6 LCA

6.1 Construction

6.1.1 MC Cubes

The small BESS contains 2 "MC Cube" units manufactured by BYD. The MC Cube contains LFP (lithium iron phosphate) battery cells for the BESS, a liquid cooling system, a fire suppression system and the battery management system. Each of the MC Cubes weighs 3,817 kg and the breakdown of the weight of the equipment within each MC Cube has either been taken from available data or has been estimated. An image of the MC Cube is shown in Figure 2.



Figure 2: MC Cube

For the battery cells, various sources of data giving the carbon intensity of LFP batteries have been reviewed and an average of the relevant figures has been taken [3,4,5,6]. The values range between 55 $kgCO_2e/kWh$ and 91.2 kgCO2e/kWh, with the mean being 75.43 kgCO2e/kWh. As the MC Cubes have a battery capacity of 447 kWh, the total from the 2 units is 894 kWh [7]. The associated carbon emissions from the manufacture of the battery cells are therefore 67,432 $kgCO_2e$.

The other materials and pieces of equipment within the MC Cubes and their embodied carbon emissions are shown in the table below. The values quoted are for the Project (i.e., twice the values for a single MC Cube). The HVAC and fire alarm systems are assumed to be similar in terms of carbon emissions to small electronic items. For the manufacturing of the component parts of the MC Cubes, the carbon emissions are already accounted for with the battery cells. For the rest of the components a factor of 30% of the emissions to create the materials has been used to estimate the emissions of the manufacturing process, giving emissions of 1,575 $kgCO_2e$. The 30% figure has been used in the absence of available data and is based on DNV's knowledge of energy inputs for other items.

Material/Equipment	**Quantity required (kg)**	**Embodied carbon ($kgCO_2e/kg$)**	**Carbon emissions ($kgCO_2e$)**
BMS	40	29.39 [8]	1,176
HVAC system	40	5.65 [9]	226
Cooling liquid	240 [10]	15.9 [11]	3,816
Fire alarm system	6	5.65 [9]	33.89
Fire alarm aerosol	0.64 [12]	2.38 [13]	1.52
Casing	446[1]	2.43 [14]	1,084
Total (excluding battery cells)	-	-	6,337
Manufacturing (excluding battery cells)	-	-	1,575
Battery cells	6,861	-	67,432
Total			**75,344**

Table 1: MC Cube Components

There are additional carbon emissions that could be factored in, such as transport of the raw materials to the MC Cube manufacturing plant, although there are significant uncertainties in this depending on where the materials come from, but these are considered to be much less significant than the embodied carbon emissions associated with the extraction of the materials and so these emissions have not been considered here.

6.1.2 PCS and Transformer Cabinet

The main components of the small BESS are 3 cabinets, 2 of which being the MC Cubes considered in the previous section, and a 3rd cabinet containing various pieces of equipment, including:

[1] Based on the surface area of the cube in the product datasheet. Assuming 2mm thickness of hot rolled coil steel.

- Power conversion system (PCS) – also referred to as an inverter
- Transformer
- Uninterruptable power supply (UPS), including lead-acid batteries
- Various electrical items, including contactors, pre-charging resistor, copper bar, wires and cables

As with the MC Cubes, the constituent materials and equipment have been identified in order to estimate the associated carbon emissions. Also included are the emissions associated with transporting the PCS and transformer from where they are manufactured to the BYD facility where the cabinet is put together.

The gross weight of the 3rd cabinet is 2,016 kg [15], with 1,300 kg of this being the transformer [16], 98 kg being the PCS [17] and 206 kg being packaging and materials to protect the cabinet in transit [15]. The remaining 412 kg accounts for the cabinet, which is assumed to be the same as that used for the MC Cube (223 kg), lead-acid batteries for the UPS (assumed to be 66 kg, consisting of 2 33 kg batteries [18]), which leaves 123 kg which is assumed to be various electrical items and pieces of equipment.

The transformer is a dry-type and therefore has no mineral oil within it for cooling, as cooling is done by the air. The transformer weighs 1,300 kg and this is estimated, based on information available for other transformers, to be made up of 830 kg of a steel core, 450 kg of copper coil and 20 kg of electronic equipment. For the steel core, 3.2% (26.6 kg) is estimated to be silicon [19] with the rest (803.4 kg) being steel.

For the PCS, the breakdown of constituent components has been estimated based on available data for similar equipment [20], which accounts for the 98 kg weight, and also gives the energy inputs required for the manufacture of the PCS.

For the 206 kg of packaging and protection required for the 3rd cabinet, 80% of the weight of this is assumed to be metal (electrogalvanized steel) and 20% of the weight is assumed to be plastic (expanded polystyrene).

Table 2 below shows the emissions associated with the materials for the 3rd cabinet, while Table 3 shows the emissions required for the manufacturing process associated with the PCS.

Material/Equipment	Quantity required (kg)	Embodied carbon ($kgCO_2e/kg$)	Carbon emissions ($kgCO_2e$)
Transformer - steel (galvanised)	223	3.03 [14]	676
Transformer - silicon steel core - Si	27	10.30 [21]	274
Transformer - silicon steel core - Steel (cold rolled)	803	2.73 [14]	2,193
Transformer - copper coil	450	2.71 [14]	1,220
Transformer - Electronics	20	24.87 [9]	497
PCS Inverter - Aluminium	41	14.60 [14]	599
PCS Inverter - Copper	16	5.73 [14]	93
PCS Inverter - Steel	8	2.73 [14]	21
PCS Inverter - Polypropylene	8	4.49 [14]	34
PCS Inverter - Polycarbonate	2	7.62 [14]	13
PCS Inverter - Iron	8	2.73 [14]	21
PCS Inverter - Electronics	16	24.87 [9]	393
Cabinet 3 - Electronics	123	24.87 [9]	3,058
Cabinet 3 - lead-acid battery	66	1.31 [9,13,14]	86
Casing and miscellaneous components	223	3.03 [14]	676
Packaging for cabinet 3 - metal (80%)	165	3.03 [14]	499
Packaging for cabinet 3 - plastic (20%)	41	3.29 [14]	136
Total			**10,488**

Table 2: 3rd Cabinet Components

Energy type	Energy required [20]	Embodied carbon ($kgCO_2e$/unit)	Carbon emissions ($kgCO_2e$)
PCS Inverter - Electricity (kWh)	90	0.58 [22,23]	52
PCS Inverter - Light fuel oil (kWh)	1	0.35 [9]	0
PCS Inverter - Natural gas (kWh)	8	0.44 [9]	4
PCS Inverter - Heat (kWh)	22	0.44 [9]	10
Total			**65**

Table 3: 3rd Cabinet Energy Inputs

For some of the equipment and materials listed in Table 2 above, the embodied carbon figure only accounts for the raw materials and does not include the carbon emissions associated with creating the final product, while in some instances this is included. For the transformer, as the embodied carbon figure does not account for the manufacture of the final product, the carbon emissions for this stage have been estimated by including an additional 30% of the emissions to produce the raw materials resulting in an additional 1,309 $kgCO_2e$. The 30% factor is based on DNV's knowledge of such factors for other equipment.

As the PCS and transformer will be transported to BYD's facility in Nanning, China in order to be included in the 3rd cabinet, the emissions associated with this have also been calculated. The PCS is manufactured in Wuxi, China by Sineng Electric Co. Ltd, while the transformer is manufactured by DongGuan DaZhong Electronic Co. Ltd in Dongguan, China. These locations are 1,909 and 640 km from BYD in Nanning. With the PCS weighing 98 kg and the transformer weighing 1,300 kg, this results in 17.2 kgCO2e from the transport of the PCS and 76.6 kgCO2e from the transport of the transformer. This is based on the UK values for freighting goods of 0.092 kgCO2e/tonne-km (including well-to-tank emissions) [9]. In China the equivalent emissions may be higher, but the overall emissions from the transport of these items are unlikely to be significant even if they may be higher than the value calculated in this LCA.

Therefore, the total emissions associated with the manufacture of these items is **11,956** $kgCO_2e$.

6.1.3 Other Materials

The other materials required to manufacture a small BESS site are:

- Concrete and rebar to form the base
- Steel Paladin fencing around the perimeter
- Cabling for the equipment and for the connection to the grid by the Distribution Network Operator (DNO)

Details of the concrete plinth that forms the base of the BESS have been taken from information provided by AMP Clean Energy [24], which indicate that the plinth is approximately 4.3 m x 6 m x 0.225 m, with an additional 0.05 m deep blinding layer. This gives a total volume of 7.1 m^3 of concrete, which equates to 17,028 kg [25].

For the rebar within the concrete plinth, the data provided indicates that this will consist of H-type 2 deformed bars, with 2 layers of reinforcement. For the area of the concrete plinth, this equates to a total of 318 kg of steel reinforcement. While the rebar will displace some of the volume of the concrete, this has not been subtracted from the quantity of concrete required as there is likely to be some wastage during the installation of the plinth.

A 0.15 m deep layer of hardcore aggregate is also required beneath the concrete plinth, which requires 3.87 m3 of material weighing 8,514 kg.

Fencing is required around the boundary of the concrete plinth, meaning 20.6 m of fencing is required. AMP Clean Energy have confirmed that 2.4 m tall Paladin fencing is to be installed. At 33.5 kg for each 3 m section of this type of fencing [26], this equates to 230 kg of steel required for the fencing (it has been assumed that the access gate will be similar in terms of weight to the fencing).

AMP Clean Energy have confirmed that 8 m of cable is required, which will be H07RNF 150mm CSA cables (single core ran in parallel, 2 single core cables capable of 347A). Data for this type of cable shows that it weighs 1,748 kg/km [27], giving a total weight of 14.0 kg. The 150 mm^2 cross sectional area has been used to calculate the volume of copper conductor within the cable, which equates to 0.0012 m^3, giving a weight of 10.7 kg of copper [28], meaning the weight of the plastic insulation will be 3.3 kg.

This cabling is in addition to a further 15 m of cabling for the DNO connection, which has been confirmed to be 15V phase to phase, 4-core cable and either 95 or 120 mm^2 cross sectional area cable (120 mm^2 cross sectional area cable has been used for this LCA). This type of cable weighs 6,546 kg/km [27], giving a total weight of 98.2 kg. The 120 mm^2 cross sectional area for the 4 cores has been used to calculate the volume of copper conductor within the cable, which equates to 0.0072 m^3, giving a weight of 64.3 kg of copper [28], meaning the weight of the plastic insulation will be 33.9 kg.

Material/Equipment	**Quantity required (kg)**	**Embodied carbon ($kgCO_2e/kg$)**	**Carbon emissions ($kgCO_2e$)**
Concrete (plinth)	17,028	0.13 [9]	2,243
Rebar	318	2.73 [14]	868
Hardcore	8,514	0.70 [14]	5,960
Steel fencing, 20.6m x 2.4m (Paladin)	230	3.03 [14]	697
Cable - copper conductor and armour	75	2.71 [14]	203
Cable - plastic insulation/sheath (PVC)	37	3.40 [14]	126
Total			**10,097**

Table 4: Project Construction Materials

For some of the equipment and materials listed in Table 4 above, the embodied carbon figure only accounts for the raw materials and does not include the carbon emissions associated with creating the final product, while in some instances this is included. For the cables, as the embodied carbon figure does not account for the manufacture of the final product, the carbon emissions for this stage have been estimated by including an additional 30% of the emissions to produce the raw materials resulting in an additional 99 $kgCO_2e$. For the fencing the carbon emissions for this stage have been estimated by including an additional 20% of the emissions to produce the raw materials, as this is considered to require less manufacturing resources than the cabling, resulting in an additional 139 $kgCO_2e$. The 20% and 30% factors are based on DNV's knowledge of such factors for other equipment.

Therefore, the total emissions associated with the manufacture of these items is 10,097 + 99 + 139 **= 10,336** $kgCO_2e$.

6.1.4 Transport to the Project Site

In order to construct the Project, the equipment and materials will need to be transported to the Project site. The main equipment and materials considered, where they are likely to come from and how they are assumed to be transported to site are:

- MC Cubes and 3rd cabinet from BYD in Nanning, China. Transported by road and ship.
- Replacement PCS from Sineng Electric Co. Ltd in Wuxi, China. Transported by road and ship.
- Cable from Eland Cables in Doncaster, UK. Transported by road.
- Paladin fencing from a local supplier (Southend on Sea, UK). Transported by road.
- Concrete and rebar from a local supplier (Colchester, UK). Transported by road.
- Also considered is transport from the site of a skip for excavated soil. Transported by road to a local waste disposal contractor (an estimate for the distance to this site has been made as there are various options).

Using the distances and time tool on Searates.com, the journey of the items of equipment from overseas locations to the Project site has been determined, which includes the distance to a port by road and then the distance from that port to the UK by ship (using Tilbury as the port for equipment assumed to be travelling by ship). Using data for CO_2e emissions associated with transport, assuming an average-laden articulated truck is used to transport the equipment to a port and an average container ship is used for the sea journey between ports allows the CO_2e emissions for the transport of these materials to be estimated, as summarised in Table 5 below. The CO_2e estimates are based on figures of 0.0921 $kgCO_2e$/tonne-km for the road transport and 0.0198 $kgCO_2e$/tonne-km for the shipping [9] and the weights of equipment detailed in previous sections. These emissions include well-to-tank emissions.

Equipment	**Total distance by road (km)** [2]	**Originating port**	**Destination port**	**Distance by sea (km)** [29]	**CO_2e (kg)**
MC Cubes	202	Fangcheng	Tilbury	17,730	2,818
3rd cabinet	202	Fangcheng	Tilbury	17,730	668
Replacement MC Cubes	202	Fangcheng	Tilbury	17,730	2,818
Replacement PCS	151	Zhangjiagang	Tilbury	19,178	39
Total – Initial equipment					**3,487**
Total – Replacement equipment					**2,857**

Table 5: Transport CO_2e for Equipment from Overseas

The other materials and equipment are assumed to come from UK suppliers. The CO_2e emissions associated with these have been calculated in the same way as for the main equipment above (note that there are no emissions from sea or air transport in this instance). For the excavated material removed by skip, the volume of this has been calculated based on the volume of concrete required, with this then converted to a weight based on a density of 2.65 kg/m^3 for soil [30], meaning 15.4 tonnes of soil would be removed.

[2] Calculated using Google Maps

Material/product	Distance to Project site (km)[3]	CO_2e (kg)
Concrete plinth	2.5	3.9
Rebar	2.5	0.1
Cable	292	3.0
Boundary fence	75	1.6
Excavated soil	20	47
Total		**55.8**

Table 6: Transport CO_2e for Equipment from the UK

Therefore, the total emissions associated with transport of initial equipment and materials is:

- 3,487 (transport of initial equipment from overseas) + 55.8 (transport of initial equipment from UK) = **3,543 $kgCO_2e$**

There is then a further 2,857 $kgCO_2e$ from the transport of replacement equipment in the operation stage.

6.1.5 Construction Activities

In addition to the construction materials considered in previous sections, the activities associated with the construction of the Project will also have an environmental impact. The calculations for the carbon emissions have been based on the construction work taking 10 working days for civils, 3 days for installing cables, 3 days for the BESS to be connected to the grid and 1 day for resurfacing (based on construction time advised by the main contractor). The main impacts are considered to be associated with the use of diesel for powering plant, with no electricity from the grid required. There are welfare vans available now that have solar panels to power them. Assuming one of these welfare vans is used, then the emissions associated with the welfare unit will be negligible and have not been included. Diesel usage has been estimated based on the activities and plant required for construction. A mini excavator is required and it has been assumed that this will be used for 4 hours per day during the civils and resurfacing works (11 days). At 3 litres of fuel per hour during use [31], this equates to 132 l of diesel for the mini excavator. A wacker is also required, it has been assumed that this will be used for the same duration as the mini excavator and at 1 litre of fuel used per hour [32] this will use 44 l of diesel. Finally, a generator is required to power a welder, which has been assumed to be required during the civils works (10 days) for 1 hour per day. At 3.8 litres of fuel used per hour [33], this required 38 l of diesel. Therefore, a total of 214 l of diesel will be required for the construction of the site.

The carbon emissions associated with diesel use are 0.62 $kgCO_2e$/litre for well to tank emissions (i.e. those associated with extraction, refining and transportation of the raw fuel sources to site prior to combustion) and 2.66 $kgCO_2e$/litre for the combustion of the diesel onsite [9], giving a total of 703 $kgCO_2e$ from the use of diesel.

The use of water onsite for drinking, cleaning, flushing toilets etc., will also have an environmental impact. In terms of carbon emissions this is minimal, assuming 4 people using 50 litres per day plus 25 l for concrete would result in 3,425 litres of water being required for the construction stage. At 0.00038 $kgCO_2e$/litre [9], which includes water supply and treatment, this equates to 1.3 $kgCO_2e$, which is insignificant compared with some of the other sources of emissions, but as water is a finite resource its use is not without other impacts. Particularly at times of drought or water shortages, the use of significant amounts of water may not be advisable or even possible.

The total carbon emissions for the activities required to construct the Project are therefore 704 $kgCO_2e$.

[3] Calculated using Google Maps

6.1.6 Change of Land Use

The Project location is in an industrial area. The footprint of the Project site is also small at 25.8 m^2, meaning that the impact of any land use change is likely to be minimal and has not been considered further in this LCA.

6.2 Operation

6.2.1 Charging and Discharging of Batteries

The approach used by AMP Clean Energy is to consider the batteries being charged at night when demand is low and can be met by renewable energy sources.

Based on a lifespan of 15 years for each set of batteries, at 1.3 cycles per day this results in a total of 7,118 cycles over the life of each battery. With an initial capacity of 0.838 MWh, an average BESS capacity of 79% over the lifetime and using a round-trip efficiency of 85.5%, the system would require 4.74 GWh in order to provide 4.05 GWh of output. This applies to each set of batteries and so the total output over a 30-year period is 8.10 GWh, which requires 9.47 GWh of input.

The carbon emissions associated with the charging of the batteries are directly correlated to the carbon intensity of the electricity used, which fluctuates based on demand and weather conditions. Data for the carbon intensity of electricity in Great Britain in the year to December 2023 has been analysed and indicates an average of 0.150 $kgCO_2e/kWh$ [34]. The carbon intensity of electricity in the UK and Great Britain has reduced significantly in recent years and it is planned that by 2035 all electricity generated will be from low carbon sources [35], which will continue to reduce the carbon intensity. By 2030, it is projected that electricity generation carbon intensity will have been reduced to 0.05 $kgCO_2e/kWh$. It is projected that by 2035 the carbon intensity of electricity generation will be 0.01 $kgCO_2e/kWh$ and by 2050 it will be 0.002 $kgCO_2e/kWh$. Assuming a linear decrease between these values, this gives an average carbon intensity of 0.063 $kgCO_2e/kWh$ during the initial 15 years of operation and 0.0048 $kgCO_2e/kWh$ for the 15-year period after the repowering of the BESS with new battery cells.

The lowest average carbon intensity for electricity generation is between 1 and 2am, which is 91.3% of the overall average at 0.137 $kgCO_2e/kWh$.

Using an overall average of 0.150 $kgCO_2e/kWh$ for the last year, taking 91.3% of this as an estimate of the average daily minima, including a factor for transmission and distribution losses (assuming the percentage these account for stays the same) and then taking 42.1% of the resulting figure to account for future decarbonisation during the initial 15 years of operation gives a value of 0.058 $kgCO_2e/kWh$ and therefore carbon emissions of **339,279 $kgCO_2e$** during the operation phase of the 1st battery cells. Following repowering of the BESS with new cells, the next operation phase will result in significantly lower carbon emissions, assuming that the decarbonisation of electricity generation decreases as planned. Based on similar calculations as above and using an average carbon intensity of 0.0044 $kgCO_2e/kWh$ for the 15 years after repowering gives carbon emissions of **25,613 $kgCO_2e$** for the 2nd operation phase, resulting in a total over the lifetime of the BESS of **364,892 $kgCO_2e$**.

6.2.2 Energy Consumption

A small amount of electrical power will be required to operate electrical equipment within the BESS. No data is available to confirm what the power usage will be, so it has been assumed that the amount used will be 1% of the total required for battery charging, meaning that the carbon emissions associated with the power use will be 1% of the values for the charging of the batteries, i.e., 3,393 $kgCO_2e$ during the first 15 years of operation and 256 $kgCO_2e$ during the 15 years after repowering.

6.2.3 Refrigerant Gas Leakage

The cooling system within the BESS uses R410A refrigerant, which is a greenhouse gas with a global warming potential (GWP) of 2,088 [36]. Each MC Cube contains 1.5 kg of refrigerant gas, with a leakage rate of less than 2 g per year

(0.13% initially. This results in the loss of approximately 30 g of refrigerant for each MC Cube. With 2 such units in place for 2 15-year periods, and with a GWP of 2,088 the carbon emissions from the leakage of the refrigerant are 248 $kgCO_2e$.

6.2.4 Maintenance, Repairs and Repowering

During the operation of the BESS there will be operation and maintenance (O&M) activities to keep the BESS working efficiently. AMP Clean Energy have advised that a round-trip of 40 miles (64 km) every 6 months will typically be required. For an average van, the carbon emissions are 0.29 kgCO2e/km, including well-to-tank emissions [9]. Over 30 years this equates to 1,112 $kgCO_2e$. Over time, the carbon intensity of travel is likely to reduce, for example through the use of electric vehicles. This would make this figure an over-estimate, but there are likely to be some emissions from basic maintenance that are hard to quantify (e.g., from the use of lubricants, repair/replacement of small parts, removal of vegetation) and so this figure can account for some of these emissions.

During the 30-year lifespan of the site the MC Cubes will be replaced after 15 years, resulting in a further 75,344 $kgCO_2e$ of emissions using the same calculations as for the initial MC Cubes. However, this figure may be lower as industries and transport gradually decarbonise, meaning the production of the batteries and other equipment, plus the transportation of them to the Project site, will result in fewer carbon emissions at the repowering stage. In the absence of any projections of this decarbonisation in the future, this has not been taken into account in this LCA.

It has also been assumed that the PCS will need to be replaced once during the operational lifespan, again using the data for the initial PCS this results in further emissions of 1,239 $kgCO_2e$. Finally, the transport of the replacement MC Cubes and PCS will result in emissions of 2,857 $kgCO_2e$ using the same basis for the calculations as for the transportation stage of site construction.

6.3 Decommissioning

6.3.1 Recycling of Batteries

After approximately 7,118 charging and discharging cycles over 15 years, the battery cells will be removed and taken for recycling. After the first set of cells reach the end of their life it is assumed that both MC Cubes are removed and replaced, including the battery cells within them, while the rest of the equipment in the 3rd cabinet will remain in situ. At the end of the life of the second set of cells, the equipment and fencing will be removed and the rest of the site will be left (i.e., the concrete and the cables). Due to the rapid recent increase in demand for LFP batteries there has been increasing focus on the fate of these batteries at the end of their life. Recycling these batteries can be economically unattractive due to a lack of value in the recovered materials, unlike NMC (lithium-nickel-manganese-cobalt oxide) batteries. However, due to the number of these batteries being produced today there are likely to be rapid developments in the way these batteries are recycled in the coming years, and so at the end of their life there may be different recycling options to those available now.

Currently, emissions associated with the recycling of Li-ion batteries are approximately 15 $kgCO_2e/kWh$ [37], which would result in emissions of **26,820 $kgCO_2e$** to recycle the cells from all 4 MC Cubes over the 30-year lifespan.

As recycling technologies develop, the carbon emissions associated with them is likely to change and this LCA can be updated to take account of this as and when new data is available.

While the recycling of the batteries results in further carbon emissions, the process results in the recovery of materials that can be used again for new LFP batteries. The recycling of the batteries can reduce the emissions associated with the production of new LFP batteries by 32% [38]. With the initial manufacture of the cells resulting in emissions of 67,432 $kgCO_2e$, this means that 21,578 $kgCO_2e$ could be saved by the recycling of each set of battery cells, or 43,157 $kgCO_2e$ over the entire 30-year lifespan. However, the 32% reduction figure is the overall reduction as a result of recycling and includes the emissions associated with the recycling process, i.e., the 26,820 $kgCO_2e$ noted above,

meaning that after the recycling process the total emissions reduction from the recovery of materials from the battery are **69,977** $kgCO_2e$.

6.3.2 Decommissioning Activities

It has been assumed that decommissioning activities will be similar in scale and scope to the construction activities, but that as the concrete plinth and cables are being left in-situ the emissions will be approximately half of what they were for the construction activities, and so the carbon emissions are estimated to be **352 $kgCO_2e$.**

Equipment and materials will also need to be removed from the site during decommissioning. A total of 17,612 kg of equipment and materials are to be removed in total, with 13,723 kg of this weight being the battery cells. Assuming travel of 100 km to a battery recycling facility and 13 km to a waste facility for the other waste items (based on the location of such a facility near the Colchester site), this results in emissions of 236 $kgCO_2e$, assuming transportation will be done in a 100%-laden rigid HGV (> 17 tonnes) [9].

6.3.3 Material Recovery

It has been assumed that the steel, iron, copper and aluminium components can all be recovered and recycled, along with the lead from the lead-acid UPS batteries. Table 7 summarises the materials that can be recovered and the carbon benefits of doing so.

Material	**Quantity (kg)**	**Carbon benefit ($kgCO_2e$/kg)**	**Carbon emissions saved ($kgCO_2e$)**
Steel & iron	2,402	1.41 [14]	3,387
Copper	512	1.41 [14]	722
Aluminium	247	10.25 [14]	2,530
Lead	36	1.09 [14]	40
Total	**3,198**		**6,679**

Table 7: Recovery of Other Materials

The R410A refrigerant can be reclaimed and re-used and as such the only emissions associated with the use of this product come from any leakage, which is accounted for in 6.2.3 and the emissions associated with the manufacture and supply of this gas are offset by its re-use at the decommissioning stage.

For all other materials (692 kg) it has been assumed that there are no further benefits from material recovery. These materials include plastics and other materials that may not be easily or feasibly recycled.

6.5 Summary & Other Environmental Impacts

6.5.1 Total CO2e Emissions

The total carbon emissions calculated during each stage of the LCA in the sections above are summarised in Table 8 below:

LCA stage	Calculated carbon emissions ($kgCO_2e$)	Percentage of total initial emissions
Manufacture – Initial MC Cubes	75,344	13.0%
Manufacture – Other equipment and materials	22,292	3.9%
Transportation of equipment and materials	3,543	0.6%
Construction activities	704	0.1%
Operation – Charging and discharging of batteries	364,892	63.1%
Operation – Energy inputs and refrigerant leakage	3,897	0.7%
Operation – O&M, including repowering	80,552	13.9%
Recycling process for LFP batteries	26,820	4.6%
Decommissioning	588	0.1%
Total before material recovery	578,633	100.0%
Benefits of battery cell recovery	-69,977	-12.1%
Benefits of other material recovery	-6,679	-1.2%
Total	501,978	

Table 8: Summary of LCA Stages and Associated Emissions

As per Section 6.2.1 the total energy generated over the lifetime of each set of battery cells is 8.10 GWh, which required 9.47 GWh of electricity input (based on a round trip efficiency of 85.5%), which means the total emissions give a value of **0.062 kgCO2e/kWh of energy generated**.

The emissions calculated are dependent on the carbon intensity of the electricity from the National Grid used to charge the batteries, which is variable and at times will be hard to predict. Excluding the carbon emissions from charging the batteries results in a figure of 0.017 $kgCO_2e$/kWh for the energy generated, and the overall figure can be calculated by adding this to the carbon intensity of the electricity used to charge the batteries to give an overall figure.

6.5.2 General

Benefits of LFP batteries over some alternatives are that they do not require rare metals to be extracted and are environmentally safe in that they do not contain any acids or other substances that could be released and harm the environment. The focus in this LCA is the carbon emissions associated with the BESS as the reason these sites are

being built is to reduce such emissions as economies strive to decarbonise and limit the impacts of climate change. Some of the other environmental impacts are summarised in the following sections.

6.5.3 Waste

Waste streams during the construction phase should be limited to items of general waste, such as household type waste from welfare facilities, and excavated soils or materials. No demolition or removal of existing structures (which would result in waste materials) is required and no hazardous waste or wastewater discharges are anticipated. Once the site is operational there should be limited waste from the site, potentially small amounts of general waste but no hazardous wastes are anticipated as it has been assumed that limited maintenance will be required to keep the BESS operational.

The recycling stage of the batteries is where the main source of waste may be produced. In the 15 years it is calculated for the batteries to go through their 7,118 cycle lifetime it is likely that the recycling process will be improved in order to recover as many of the battery materials as possible. However, any wastes from the battery cells that are not recyclable or re-useable will need to be disposed of in other ways, e.g. incineration or landfill, both of which have adverse environmental impacts.

6.5.4 Pollution

Providing the construction and operation of the site, and the recycling of the battery cells, is done in accordance with relevant legislation and managed to prevent incidents resulting in the release of hazardous substances to the environment, the direct impact of pollution from the BESS will be minimal as there are no planned discharges to land or watercourses. The use of diesel will result in emissions to air, with the carbon emissions accounted for in previous sections, while there will also be particulate matter released which will contribute to a reduction in the local air quality, although the impacts of this are likely to be minimal.

6.5.5 Nuisance

Given the location of the site it is not considered likely that it will cause any nuisance. Once constructed, the site should not produce noise, vibration or odour that would be detectable by any neighbours, while there will also be no light pollution and when situated in an industrial area, there should also be limited visual impact caused by the site.

8 CARBON FOOTPRINTING (CFP STUDY)

Total lifetime emissions have been calculated to be 578,633 $kgCO_2e$, all of which is from fossil carbon, with no emissions from biogenic carbon. None of the emissions are associated with land use change as these emissions are considered to be negligible, while there are no emissions from aircraft transportation.

Considering the recycling of battery cells and other equipment when they reach the end of their life or the Project reaches the end of its lifespan, 76,655 $kgCO_2e$ of emissions may be prevented. This includes the recycling of steel, iron, copper, aluminium and lead during decommissioning compared with the production of virgin metals. The recycling and decommissioning processes for the battery cells and other equipment material results in emissions of 27,408 $kgCO_2e$, so the net benefit of recycling is 49,247 $kgCO_2e$ of emissions saved.

A summary of the emissions, in line with ISO 14067 requirements is shown below and a breakdown in Figure 3.

GHG Emission type	**Emissions in $kgCO_2e$ over life cycle for scenario**
Fossil carbon	578,633
Biogenic carbon	0
Land use change (direct or indirect)	0
Aviation emissions (included in fossil carbon figure)	0
Total emissions	578,633 (27,408 of which is from recycling and decommissioning processes)
Emissions saved from material recovery	76,655 (net benefit of 49,247 after emissions of 27,408 during recycling and decommissioning)
Overall emissions	**501,978**

Table 9: Summary of CO_2e Emissions

With 8.10 GWh of electricity being exported to the grid by the Project over its lifetime, the carbon emissions per unit of output equates to 0.062 $kgCO_2e/kWh$.

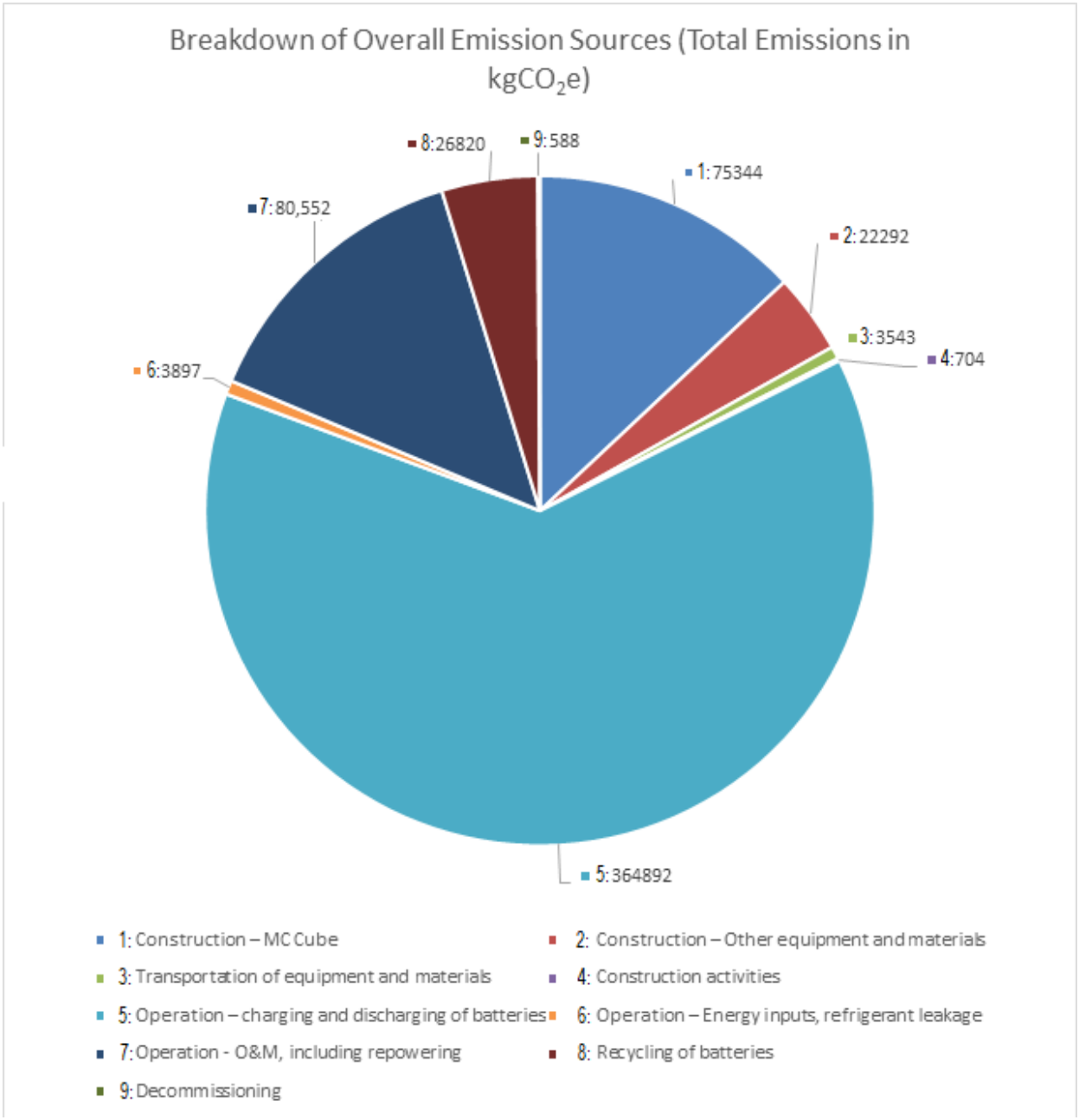


Figure 3: Breakdown of carbon emissions (excluding benefits from recycling at end-of-life)

9 CARBON SAVINGS

The lifetime emissions of 501,978 kgCO_2e from the small BESS have been compared with the emissions associated with the generation of electricity from natural gas in power stations and in gas peakers.

For natural gas-powered power stations, the emissions are 0.430 kgCO_2e/kWh [39], while for gas peakers the equivalent figure is 0.651 kg CO_2e/kWh [40]. Table 10 below shows the carbon emissions associated with generating 8.10 GWh of electricity for these power sources, compared to the small BESS.

Power Source	Emissions per unit (kgCO_2e/kWh)	Lifetime emissions over 30 years (kgCO2e)
Small BESS	0.062	501,978
Natural gas-powered power station	0.430	3,482,029
Gas peaker	0.651	5,271,630

Table 10: Comparison of Power Sources

This means that the use of the small BESS can reduce carbon emissions by 2,980,051 kgCO_2e compared with electricity generated by natural gas-powered power stations and by 4,769,652 kgCO_2e compared with gas peakers.

While the annual carbon savings will vary as a result of the decarbonisation of the electricity grid over time, the average annual carbon savings over the 30-year lifespan of the small BESS are 99,335 kgCO_2e compared with natural gas power stations and 158,988 kgCO_2e compared with gas peakers. These results are based on the LCA outputs, which are for a BESS starting operation in 2023 or 2024.

10 CONCLUSIONS AND RECOMMENDATIONS

The overall result of the LCA is that the carbon emissions associated with the lifecycle of the BESS equate to 0.062 kgCO2e/kWh of energy generated by the batteries and provided to the National Grid. This figure is based on the estimated average carbon intensity for the electricity used to charge the batteries over the 15 years of their lifetime and then the subsequent 15 years for a replacement set of cells, taking into account the variation of carbon intensity at different times and the planned decarbonisation of electricity generation over the coming years. It also takes account of material recovery at the end of the life of the battery cells and other equipment and materials onsite. The recycling of batteries means batteries can be produced in the future that do not require so many raw materials to be extracted and processed (e.g. through the recycling of the battery cells). Other materials used can also be recycled and in total, material recovery could prevent up to 76,655 kgCO_2e of emissions, although the recycling processes themselves would emit 27,408 kgCO_2e (including transport to waste disposal sites from the Project site). As electricity generation in the UK and the processes involved with creating batteries and other equipment are gradually decarbonised and fossil fuels like natural gas are phased out, the environmental benefits of the BESS, in terms of carbon emissions against power generation sources feeding into the National Grid, will decrease over time. However, battery storage is still an important part of the energy transition in terms of managing the difference in supply and demand when using renewable energy sources such as wind and solar power.

The 0.062 kgCO_2e/kWh figure compares favourably with the current figure of 0.430 kgCO_2e/kWh for electricity generated by natural gas-powered power stations (CCGT) [39], meaning that if the use of the BESS can prevent the use of fossil fuels to generate electricity, then it will be environmentally beneficial. This figure also compares favourably with the emissions associated with flexible open cycle gas plants (gas peakers), which are 0.651 kg CO_2e/kWh [40]. If these types of plants are the direct technology that will be displaced by the BESS, this is the figure that should be used as a comparison. Based on the total output of power to the grid from the small BESS over 30 years, it can save 99 tonnes of CO_2e per year on average, when compared with natural gas power stations, and 159 tonnes of CO_2e per year compared with the use of gas peakers.

The LCA is based on various assumptions and estimates, and its accuracy would be improved by updating figures if and when more accurate data becomes available. Figure 3 above shows the lifecycle stages and their contribution to the overall emissions, which shows that the charging and discharging stage of the LCA is by far the most significant contributor to the emissions, accounting for 63.1% of the total emissions (prior to accounting for any emissions reductions from material recovery) and this is therefore an important stage in terms of the overall accuracy of the LCA. The emissions for this stage are based on calculations of the carbon intensity of electricity generated in Great Britain in the coming years, based on projections of future decarbonisation and assuming that the BESS charging can take place at optimum times, i.e. when the carbon intensity is at its lowest. These calculations can therefore be revisited as new data becomes available once the BESS is operational. It should also be noted that as the emissions calculated for this stage are dependent on the carbon intensity of the electricity from the National Grid used to charge the batteries, this is variable and at times will be hard to predict. Excluding the carbon emissions from charging the batteries results in a figure of 0.017 $kgCO_2e/kWh$ for the energy generated, and the overall figure can be calculated by adding this to the carbon intensity of the electricity used to charge the batteries.

The other main contributor to the overall emissions is the manufacture of the MC Cubes containing the battery cells, accounting for 13.0% of emissions initially (again prior to accounting for any emissions reductions from material recovery). The same amount of emissions are also applied to the operational stage where the repowering event results in the MC Cubes being replaced, contributing to the O&M and repowering accounting for 13.9% of total emissions before material recovery. As the other stages account for a total of 9.1% of emissions (prior to material recovery reductions) these are less likely to be critical to the accuracy of the LCA.

Recommendations:

- Operational emissions are by far the largest area of carbon intensity and when operational data is available this should be used to update the LCA and improve its accuracy.
- Review the areas of most significant emissions and consider how emissions can be minimised for this and future projects.
- If any other data becomes available that would improve the accuracy of the LCA, either before or during the operation of the Project, this should be included in an updated LCA (unless any differences are negligible).
- Developments with LFP battery recycling should be monitored so that at the end of the life of the cells the most suitable disposal route can be determined. The LCA can also be updated to reflect developments with recycling, as they can have a major impact in the overall LCA reduction.

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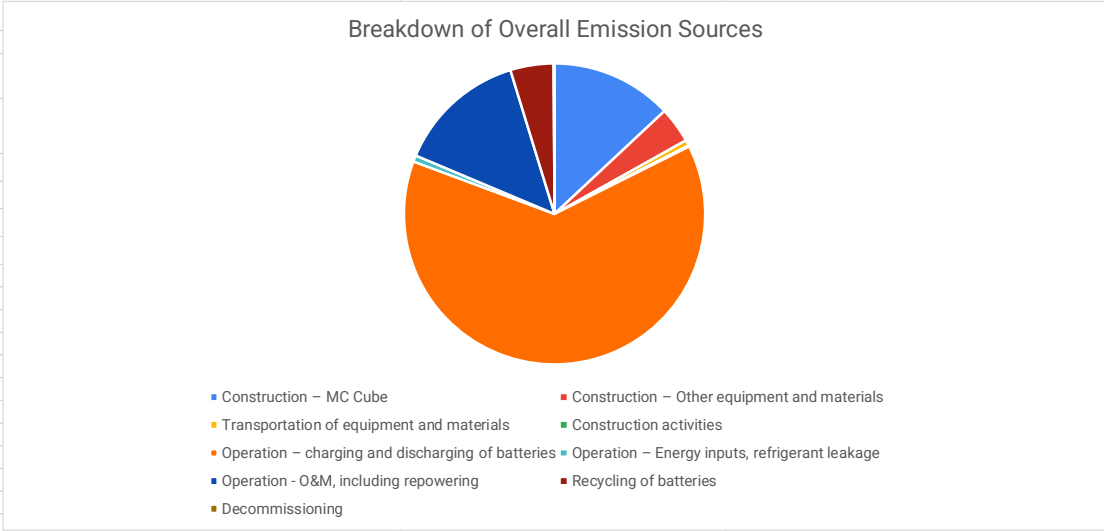
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12 APPENDIX A: LCA CALCULATIONS

BESS is enabling the penetration of IBR lower carbon footprint resources....					
LCA assessment					
Key stats		Current			
Lifespan		30	years		
Novel BESS MW (operational)		0.2	*Assumptions*		
BESS hour systems		4.19			
MWh		0.838			
kWh		838			
Daily cycles		1.5			
No. of cycles of Li-ion over life		7118			
Start of life BESS capacity (warranty)		92%			
End of life BESS capacity (warranty curve)		67%			
Average BESS capacity (over life)		79%			
Round Trip Efficiency		0.855			
Total GWh energy capacity generated over life of each set of cells		**4.0**			
Total kWh energy capacity generated over life of each set of cells		4,048,871			
CO2 saving - OUTPUT					
Target kWh of energy generated (assumed over the life of the batteries)		4,048,871			
g CO2 saved		1,490,025,666	*Driven by daily cycles, repowering considerations, BESS capacity (as per table above)*		
megatonnes of Co2 saved		**0.00**			
LCA assessment Li-ion battery		**Current**	**Actual (to be calculated once operational)**		
Stages	**Co2 footprint - kg CO2-eq/kWh GHG**	**CO2 footprint - kg Co2-eq**		**Definition**	**Source**
1/ Emissions associated with the building of the BESS		67,432		1a/ Mining and refining (of minerals / metals) for battery cells 1b/ Battery material production (including active material production - cathodes, anodes, electrolyte)	See 'Batteries' tab
		7,912		1c/ Cell production and MC Cube assembly - ie: assembly of cells with other components such as the cooling system, battery management system	See 'Batteries' tab
		3,543		1d/ Emissions associated with transportation of batteries and other materials from manufacturer to BESS sites	See 'Transport' tab
		22,292		Emissions associated with the other materials and equipment required (including mining and refining of raw materials and production of final product)	See 'Other Materials' tab
		704		Emissions associated with the construction activities for site (does not include construction materials, see above).	See 'Construction' tab
2/ Emissions associated with the use-phase (ie charging and discharging of the battery)		364,892		Emissions associated with the charging and discharging of the battery	See calculations above and 'Operation' tab
		3,897		Emissions associated with the operation of the BESS site	See 'Operation' tab
		79,440		Replacements/repowering	
		1,112		O&M	
3/ End of life / disposal emissions		26,820		This carbon footprint assumes battery cell recycling in the end-of-life phase.	
		588		Emissions associated with the decommissioning of the site, including transport to disposal site.	See 'Decom' tab
		-69,977		Emissions saved from battery cell recovery	See 'Decom' tab
		-6,679		Emissions saved from recovery of other materials	See 'Decom' tab
Total footprint for AMP BESS cells procured	**0.00**	**501,978**	**TBD**		

Total footprint / kg CO2 eq / kWh (cradle to grave)	0.062
Total footprint / g CO2 eq / kWh (cradle to grave)	62.0
Total footprint / g CO2 eq / kWh (cradle to grave) - excluding charging	16.9

Stage	Emissions (kgCO2e	Percentage of total emissions
Construction – MC Cube	75344	13.0%
Construction – Other equipment and materials	22292	3.9%
Transportation of equipment and materials	3543	0.6%
Construction activities	704	0.1%
Operation – charging and discharging of	364892	63.1%
Operation – Energy inputs, refrigerant	3897	0.7%
Operation - O&M, including repowering	80,552	13.9%
Recycling of batteries	26820	4.6%
Decommissioning	588	0.1%
Total before material recovery benefits	578633	100.0%
Battery cell recovery	-69977	-12.1%
Other material recovery	-6679	-1.2%
Total	501978	



Constituent material	Quantity required (kg)	Carbon (kgCO2e)	Contribution to emissions per kWh capacity	
Battery cells		67432		
		0		
		0		
		0		
		0		
		0		
		0		
		0		
		0		
		0		
Cells - Total		**67432**	**80**	**kgCO2e/kWh**
BMS	40	1176		
HVAC	40	226		
Cooling liquid	240	3816		
Fire alarm	6	33.89		
Fire alarm aerosol	0.64	1.52		
Casing	446	1084		
Additional MC Cube components		**6337**	**7.56**	**kgCO2e/kWh**
MC Cube manufacturing		**1575**	**1.88**	**kgCO2e/kWh**
Repowering		**75344**	**90**	**kgCO2e/kWh**
Total		**150689**	**90**	**kgCO2e/kWh**

Substance	Embodied Carbon	
Aluminium	12.70	kgCO2e/kg
Lithium iron phosphate	26.43	kgCO2e/kg
Graphite carbon	5.32	kgCO2e/kg
Polymer	3.12	kgCO2e/kg
Copper	5.85	kgCO2e/kg
Hexafluoropropylene-vinylidene fluoride Copolymer	3.12	kgCO2e/kg
Electricity	0.58	kgCO2e/kWh
Lithium Hexafluorophosphate	15.77	kgCO2e/kg
Acetylene Black	2.05	kgCO2e/kg
Diethyl Carbonate	3.20	kgCO2e/kg
Dimethyl Carbonate	3.20	kgCO2e/kg
Ethyl Methyl Carbonate	3.20	kgCO2e/kg
Propylene Carbonate	3.20	kgCO2e/kg
Ethylene Carbonate	3.20	kgCO2e/kg
Steel (hot rolled coil)	2.43	kgCO2e/kg
Refrigerant	15.90	kgCO2e/kg
Water	0.00038	kgCO2e/kg
Small electronics	5.65	kgCO2e/kg
Electrical items - IT	24.87	kgCO2e/kg
Firefighting aerosol - potassiu	2.38	kgCO2e/kg

Battery data		
MC Cube weight	3817	kg
MC Cube kWh	447	kWh
MC Cubes on site	2	
Total kWh	894	kWh
BMS	20	kg
HVAC	20	kg
Cooling liquid	120	kg
Fire alarm	3	kg
Aerosol	0.32	kg
Casing	223	kg
Weight of cells per cube	3430.661	kg
Total weight of cells	6861.322	

Energy use to create battery, per energy output (kWh/kWh)	Carbon (kgCO2e/kWh)	Total carbon (kgCO2e)
50.00	29.01	24309

LFP battery carbon intensity	
55	kgCO2e/kWh
82.5	kgCO2e/kWh
73	kgCO2e/kWh
91.21	kgCO2e/kWh
67432.185	kgCO2e

75.4275

BMS	
29.39	kgCO2e/kg

Cell composition from SDS		Value assumed	Amount required	
Graphite	7-25%	14%	432	kg
LiFePO4	15-40%	30%	926	kg
Hexafluoropropylene-vinylidene fluoride Copolymer	3-15%	7%	216	kg
Lithium Hexafluorophosphate	0-5%	3%	93	kg
Acetylene Black	0-2%	1%	31	kg
Diethyl Carbonate	0-15%	9%	278	kg
Dimethyl Carbonate	0-15%	9%	278	kg
Ethyl Methyl Carbonate	0-15%	9%	278	kg
Propylene Carbonate	0-15%	9%	278	kg
Ethylene Carbonate	0-15%	9%	278	kg
Aluminium (assume 10% of weight)			343	kg

Substance	Quantity required (kg)	Carbon factor (kgCO2e/kg)	Embodied CO2e (kg)	Additional factor for manufacture (kgCO2e)	Contribution to emissions per kWh capacity	
Concrete (plinth)	17028	0.13	2243			
Rebar	318	2.73	868			
Steel fencing, 20.6m x 2.4m (Paladin)	230	3.03	697	139		
Transformer - steel (galvanised)	223	3.03	676	1309		
Transformer - mineral oil	0	1.40	0			
Transformer - silicon steel core - Si	27	10.30	274			
Transformer - silicon steel core - Steel	803	2.73	2193			
Transformer - copper coil	450	2.71	1220			
Transformer - Electronics	20	24.87	497			
Cable - copper conductor and armour	75	2.71	203	99		
Cable - plastic insulation/sheath (PVC)	37	3.40	126			
Hardcore	8514	0.70	5960			
PCS Inverter - Aluminium	41	14.60	599			
PCS Inverter - Copper	16	5.73	93			
PCS Inverter - Steel	8	2.73	21			
PCS Inverter - Polypropylene	8	4.49	34			
PCS Inverter - Polycarbonate	2	7.62	13			
PCS Inverter - Iron	8	2.73	21			
PCS Inverter - Electronics	16	24.87	393			
PCS Inverter - Electricity (per kWh)	90	0.58	52			
PCS Inverter - Light fuel oil (per kWh ne	1	0.35	0			
PCS Inverter - Natural gas (per kWh ne	8	0.44	4			
PCS Inverter - Heat (per kWh net)	22	0.44	10			
PCS Inverters - replacement - see operation						
Cabinet 3 - Electronics	123	24.87	3058			
Cabinet 3 - lead-acid battery	66	1.31	86			
Casing and misc components	223	3.03	676			
Packaging for cabinet 3 - metal (80%)	165	3.03	499			
Packaging for cabinet 3 - plastic (20%)	41	3.29	136			
Total - Cabinet 3			11862			
Total - embodied			**20651**	**kgCO2e**	**24.6**	**kgCO2e/kWh**
Manufacturing processes			**1547**	**kgCO2e**	**1.85**	**kgCO2e/kWh**
Transport of PCS and inverter to BYD			**93.88298944**	**kgCO2e**		

Transformer		
DT1136		
Total weight	1300	kg
Number required	1	
Oil volume	0	l
Oil weight	0	kg
Core weight	830	kg
Silicon weight	26.56	kg
Steel weight (core)	803.44	kg
Electronics	20	kg
Copper coil	450	kg
Steel weight (structure)	0	kg
PCS/inverter		
EH-0200-HA-M		
Weight	98	kg
Number needed	1	1500V
Total	1	
Aluminium	41	kg
Copper	16	kg
Steel	8	kg
Polypropylene	8	kg
Polycarbonate	2	kg
Iron	8	kg
Electronics	16	kg
Electricity	90	kWh
Light fuel oil	1.92	MJ
	0.53	kWh
Natural gas	30	MJ
	8	kWh
Heat	78	MJ
	22	kWh
Total weight of cabinet (inc. tra	1810	kg
Remaining weight after transfo	412	kg
Small electronics	123	kg
Lead acid battery	66	kg
Casing and misc components	223	kg
Concrete plinth		
Width	4.3	m
Length	6	m
Depth	0.225	
Rebar A393 mesh	6.16	kg/m2
Rebar weight per layer	158.928	kg
Rebar layers	2	
Rebar weight	317.856	kg
Concrete volume	5.805	m3
Blinding depth	0.05	m
Blinding volume	1.29	m3
Concrete weight	17028	kg
Type 1 hardcore depth	0.15	m
Type 1 hardcore volume	3.87	m3

PCS		
EH-0200-HA-M		
Weight	98	kg
Number needed	1	1500V
Total	1	
Aluminium	41	kg
Copper	16	kg
Steel	8	kg
Polypropylene	8	kg
Polycarbonate	2	kg
Iron	8	kg
Electronics	16	kg
Electricity	90	kWh
Light fuel oil	1.92	MJ
	0.53	kWh
Natural gas	30	MJ
	8	kWh
Heat	78	MJ
	22	kWh
Other materials		
Gross weight of 3rd cabinet	2016	kg
Packaging	206	kg
Cabling		
Length of H07RN-F EN	8	m
Weight/length	1748	kg/km
Weight	13.984	kg
Copper area	0.00015	m2
Copper volume	0.0012	m3
Copper weight	10.72	kg
Plastic weight	3.268000	kg
Length of cable to DNO connect	15.0000	m
Weight/length	6546	kg/km
Weight	98.19	kg
Copper area	0.00048	m2
Copper volume	0.0072	m3
Copper weight	64.30	kg
Plastic weight	33.894000	kg

Resource use	Quantity		Carbon factor (kgCO2e/unit)	Total CO2e (kg)	
Electricity (from grid)		kWh	0.256944289	0	
Diesel (generators, plant)	214	l	3.283461737	703	
Water	3425	l	0.000378003	1.3	
Total				**704**	**kgCO2e**
				0.84	**kgCO2e/kWh**

Mini excavator		
Number required	1	
Fuel use	3	l/h
Days required	11	
Hours used per day	4	
Total fuel	132	l

Wacker		
Number require	1	
Fuel use	1	l/h
Days required	11	
Hours used pe	4	
Total fuel	44	l

Generator - welder		
Number required	1	
Fuel use	3.8	l/h
Days required	10	
Hours used per day	1	
Total fuel	38	l

Civils	
Working days	10

Cabling	
Working days	3

UKPN	
Working days	3

Resurfacing	
Working days	1

Item(s)	Location	Port	Airport	Road distance to port/airport (km)	UK port/airport	Distance to UK port/airport (km)	Road distance to CO2 8GU (km)	Total road distance (km)	Total Road CO2 (tonnes)	Ship distance (km)	Ship CO2 (tonnes)	Air distance (km)	Air CO2 (tonnes)	Total CO2 (tonnes)	Weight of unit to be shipped (tonnes)
MC Cube	BYD, Nanning, China	Fangcheng		119	Tilbury	17730.4	83	202	0.1421	17730	2.676			2.818	7.63
PCS - transport to BYD Nanning	Wuxi, China			1909	N/A	N/A	N/A	1909	0.0172	N/A				0.017	0.10
Transformer - transport to BYD Nan	Dongguan, China			640	N/A	N/A	N/A	640	0.0766	N/A				0.077	1.30
PCS & transformer	BYD, Nanning, China	Fangcheng		119	Tilbury	17730.4	83	202	0.0337	17730	0.635			0.668	1.81
Cable	Doncaster UK						292	292	0.0030					0.003	0.11
Fencing	Southend on Sea						75	75	0.0016					0.002	0.23
Concrete	Colchester, Travis Perkins						2.5	2.5	0.0039					0.004	17.03
Rebar	Colchester, Travis Perkins						2.5	2.5	0.0001					0.000	0.32
Skip - excavated soil							20	20	0.0472					0.047	25.64
Replacement MC Cubes	BYD, Nanning, China	Fangcheng		119	Tilbury	17730.4	83	202	0.1421	17730	2.676			2.818	7.63
Replacement PCS/inverter	Wuxi, China	Zhangjiagang		68	Tilbury	19178	83	151	0.0014	19178	0.037			0.039	0.10

CO2 emissions by road		
0.092125059	kgCO2e/tonne-km	Emissions for average laden articulated lorry (>33T)

CO2 from shipping		
0.019773143	kgCO2e/tonne-km	Average container ship

Total - Initial	**3543**	**kgCO2e**
Replacements		
MC Cubes	**2818**	**kgCO2e**
PCS/Inverter	**39**	**kgCO2e**

Charging and discharging		
Average electricity carbon intensity	0.1500	kgCO2e/kWh
Average electricity carbon intensity 1am-2am	91.3%	kgCO2e/kWh
2030 carbon intensity	0.0500	kgCO2e/kWh
2050 carbon intensity	0.0020	kgCO2e/kWh
Average carbon intensity 2023-2037	0.0632	kgCO2e/kWh
Average 2023-2037 as a percentage of average	42.1%	
Average minimum carbon intensity 2023-2037	0.058	kgCO2e/kWh
Average carbon intensity 2038-2042	0.0048	kgCO2e/kWh
Average 2038-2052 as a percentage of average	3.2%	
Average minimum carbon intensity 2038-2052	0.0044	kgCO2e/kWh
Total 1st cells	**339279**	**kgCO2e**
Total 2nd cells (after repowering)	**25613**	**kgCO2e**
Total	**364892**	**kgCO2e**

Refrigerant leakage - R410A	
1.5	kg per unit
0.13%	leak rate per year
15.00	Years
2	cell lifetimes
1.47	kg left
0.03	kg lost
2088	R410A GWP
62	kgCO2e
2	units
248	**kgCO2e**

UK electricity carbon intensity (UK Gov figures)		
0.20707429	kgCO2e/kWh	Generation
0.04987	kgCO2e/kWh	Scope 3 losses

UK electricity carbon intensity		
0.1500	kgCO2e/kWh	Generation
0.03613625	kgCO2e/kWh	T&D losses

Power use		
Power (propo	0.01	
Total 1st cells	3392.791454	kgCO2e
Total 2nd cells	256.1311964	kgCO2e
Total	3649	kgCO2e

UK future decarbonisation estimates				
Year	**Projected emissions**		**Projected emissions with T&D**	
2023	0.1500	kgCO2e/kWh	0.1862	kgCO2e/kWh
2024	0.1357	kgCO2e/kWh	0.1684	kgCO2e/kWh
2025	0.1214	kgCO2e/kWh	0.1507	kgCO2e/kWh
2026	0.1071	kgCO2e/kWh	0.1330	kgCO2e/kWh
2027	0.0928	kgCO2e/kWh	0.1152	kgCO2e/kWh
2028	0.0785	kgCO2e/kWh	0.0975	kgCO2e/kWh
2029	0.0642	kgCO2e/kWh	0.0797	kgCO2e/kWh
2030	0.0500	kgCO2e/kWh	0.0620	kgCO2e/kWh
2031	0.0420	kgCO2e/kWh	0.0521	kgCO2e/kWh
2032	0.0340	kgCO2e/kWh	0.0422	kgCO2e/kWh
2033	0.0260	kgCO2e/kWh	0.0323	kgCO2e/kWh
2034	0.0180	kgCO2e/kWh	0.0223	kgCO2e/kWh
2035	0.0100	kgCO2e/kWh	0.0124	kgCO2e/kWh
2036	0.0095	kgCO2e/kWh	0.0117	kgCO2e/kWh
2037	0.0089	kgCO2e/kWh	0.0111	kgCO2e/kWh
2038	0.0084	kgCO2e/kWh	0.0104	kgCO2e/kWh
2039	0.0079	kgCO2e/kWh	0.0098	kgCO2e/kWh
2040	0.0073	kgCO2e/kWh	0.0091	kgCO2e/kWh
2041	0.0068	kgCO2e/kWh	0.0084	kgCO2e/kWh
2042	0.0063	kgCO2e/kWh	0.0078	kgCO2e/kWh
2043	0.0057	kgCO2e/kWh	0.0071	kgCO2e/kWh
2044	0.0052	kgCO2e/kWh	0.0065	kgCO2e/kWh
2045	0.0047	kgCO2e/kWh	0.0058	kgCO2e/kWh
2046	0.0041	kgCO2e/kWh	0.0051	kgCO2e/kWh
2047	0.0036	kgCO2e/kWh	0.0045	kgCO2e/kWh
2048	0.0031	kgCO2e/kWh	0.0038	kgCO2e/kWh
2049	0.0025	kgCO2e/kWh	0.0031	kgCO2e/kWh
2050	0.0020	kgCO2e/kWh	0.0025	kgCO2e/kWh
2051	0.0020	kgCO2e/kWh	0.0025	kgCO2e/kWh
2052	0.0020	kgCO2e/kWh	0.0025	kgCO2e/kWh

Replacements		
MC Cube	75344	kgCO2e
Inverter	1239	kgCO2e
Transport	2856.96033	kgCO2e

O&M		
Travel	40	miles
	64.3736	km
Trips per year	2	
Annual distance	128.75	km
Carbon intensity -	0.29	kgCO2e/km
Emissions	37.06	kgCO2e/year
Total	1111.93	kgCO2e

Recycling battery cells		
Carbon emissions due to recycling process	15	kgCO2e/kWh

Material Recovery (battery cells)		
Emissions reduction from recycling	32%	
Total emissions (initial cells)	67432	kgCO2e
Reduction achieved	21578	kgCO2e
Sets of cells	2	
Total carbon savings from recycling	43157	kgCO2e

Material Recovery (other materials)			Carbon emissions benefit			
Steel & iron - total including repowering	2402	kg	1.41	kgCO2e/kg	3387	kgCO2e
Copper - total including repowering	512	kg	1.41	kgCO2e/kg	722	kgCO2e
Aluminium - total including repowering	247	kg	10.25	kgCO2e/kg	2530	kgCO2e
Lead	36	kg	1.09	kgCO2e/kg	40	kgCO2e
Refrigerant						
Total - site plus initial components					5533	kgCO2e
Total including repowering					6679	kgCO2e

Transport		
Weight of materials to be transported for waste	17612	kg
Weight of battery cells	13723	kg
Distance to LFP recycling facility	100	km
Weight of other materials	3889	kg
Distance to waste facility	13	km
Total tonne-km	1601	tonne-km
Carbon emissions	0.147	kgCO2e/tonne-km
Total carbon emissions	236	kgCO2e

Decommissioning activities		
Assume half of construction as concrete slab and cables to remain in situ	352	kgCO2e



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