Liddell Battery and Bayswater Ancillary Works Project

Appendix I – Greenhouse Gas Assessment Detailed Methodology

Appendix I. Greenhouse gas assessment detailed methodology

GHG is a collective term for a range of gases that are known to trap radiation in the upper atmosphere, where they have the potential to contribute to the greenhouse effect (global warming). Creating an inventory of the likely GHG emissions associated with a project has the benefit of determining the scale of the emissions and providing a baseline from which to develop and deliver GHG reduction options. GHG include:

- Carbon dioxide (CO_2)– by far the most abundant, primarily released during fuel combustion
- Methane (CH_4) – from the anaerobic decomposition of carbon-based material (including enteric fermentation and waste disposal in landfills)
- Nitrous oxide (N_2O)– from industrial activity, fertiliser use and production
- Hydrofluorocarbons (HFCs) – commonly used as refrigerant gases in cooling systems
- Perfluorocarbons (PFCs) – used in a range of applications including solvents, medical treatments and insulators
- Sulphur hexafluoride (SF_6) – used as a cover gas in magnesium smelting and as an insulator in heavy duty switch gear.

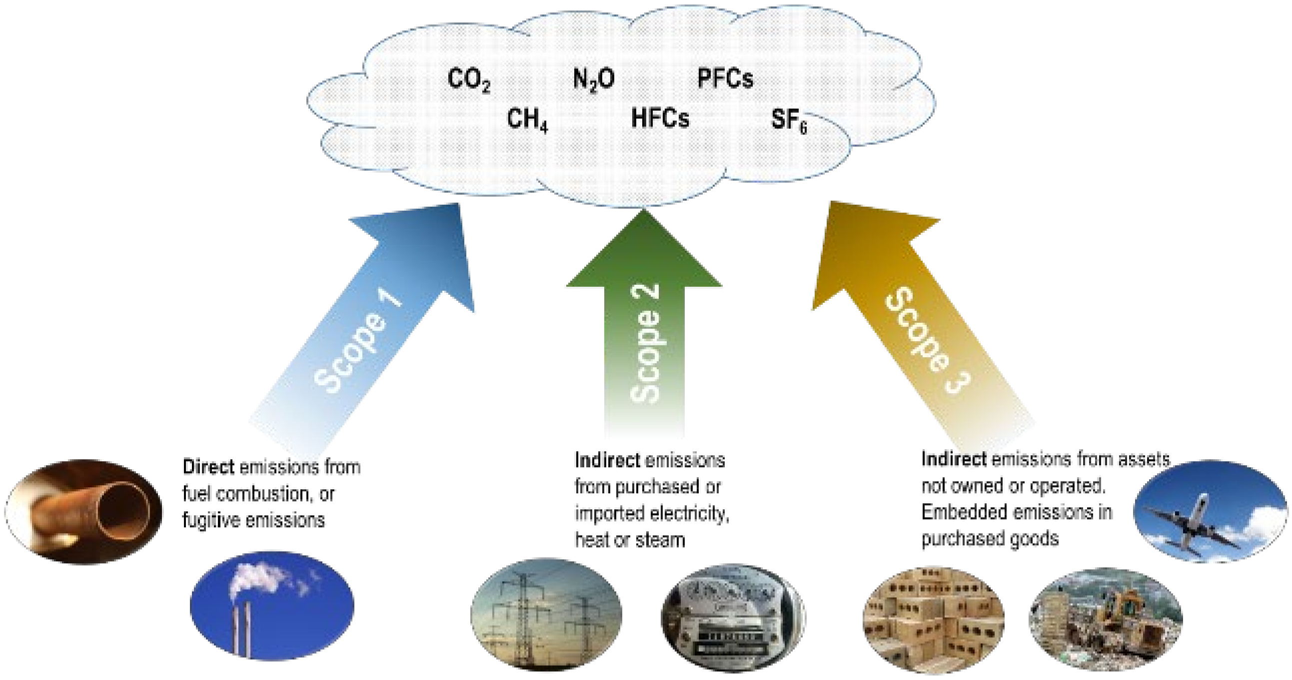
It is common practice to aggregate the emissions of these gases to the equivalent emission of carbon dioxide. This provides a simple figure for comparison of emissions against targets. Aggregation is based on the potential of each gas to contribute to global warming relative to carbon dioxide and is known as the global warming potential (GWP). The resulting number is expressed as carbon dioxide *equivalents* (or CO_2e).

The GHG inventory for this Project was calculated in accordance with the principles of the Greenhouse Gas Protocol (**GHG Protocol**)[1]. The GHG emissions that form the inventory can be split into three categories known as 'Scopes'. Scopes 1, 2 and 3 are defined by the GHG Protocol are shown in **Figure I-1** and can be summarised as follows:

- **Scope 1 –** Direct emissions from sources that are owned or operated by a reporting organisation (examples – combustion of coal in onsite generation units or combustion of diesel in company owned cars)
- **Scope 2 – I**ndirect emissions associated with the import of energy from another source (*examples – import of electricity or heat*)
- **Scope 3 –** Other indirect emissions (other than Scope 2 energy imports) which are a direct result of the operations of the organisation but from sources not owned or operated by them (*examples include emissions from activities used to make construction materials, or upstream emissions associated with raw material (e.g. coal) extraction.*)

The initial action for a greenhouse gas inventory is to determine the sources of greenhouse gas emissions, assess their likely significance, and set a provisional boundary for the study.

[1] The Greenhouse Gas Protocol is collaboration between the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The Protocol provides guidance on the calculation and reporting of carbon footprints.



Adapted from: World Business Council for Sustainable Development – Greenhouse Gas Protocol

Figure I-1: Sources of GHG

The results of this study are presented in terms of the above-listed 'Scopes' to help understand the direct and indirect impacts of the project.

The GHG Protocol (and many other reporting schemes) dictates that reporting Scope 1 and 2 sources is mandatory, whilst reporting Scope 3 sources is optional. Reporting *significant* Scope 3 sources is recommended. Within this inventory, assessment has been made of all (Scopes 1, 2 and 3) sources of GHG deemed significant to the implementation of the proposed upgrade.

I.1 Scope and boundary

The scope of this GHG assessment is focussed on the construction and operation of an up to 500 MW / 2 GWh battery which would charge during times of excess grid generation and discharge during times of peak demand. Major components of the Decoupling and BAW are also included within the assessment. The scope of the assessment includes all material emissions within the plant boundary.

The assessment boundary defines the scope of greenhouse gas emissions and the activities to be included in the assessment. **Table I**.1 and **Table I**.2 summarise the emissions sources and activities considered within the project's assessment boundary for construction and operation respectively, according to scope. Note that some emissions sources are split into more than one scope. This is typically the case where there are direct emissions (e.g. combustion of fuel in plant and equipment used as part of the project) as well as indirect emissions (such as the extraction and processing of fuel before it is used). The boundary will include all material source (and sinks) of emissions associated with construction and operation (over approximately 20 years), based on commencement of operation between 2021 and 2025 (as progressive units are installed).

Table I.1 Emission sources included in the construction GHG assessment

Emission source	Scope 1	Scope 2	Scope 3
Construction plant and equipment (site clearing / levelling and cranes, road construction only)	✓		✓
Material purchases (embedded GHGs in construction materials)			✓
Material purchases (embedded GHGs in battery componentry)			✓
Vegetation Clearance	✓		
Material transport (haulage of materials from manufacture to site)			✓

Table I.2 Emission sources included in the operational GHG assessment

Emission source	Scope 1	Scope 2	Scope 3
Electricity consumed / lost in system Round Trip Efficiency (RTE)		✓	✓

Note that electricity consumption has both Scope 2 and Scope 3 components associated with it. Scope 2 emissions, as per **Figure I-1**, relate to the emissions from the combustion of fuels used to generate electricity at the generator. Scope 3 emissions relate to the extraction and processing of the fuels used in power generation upstream from the generator.

I.2 Other emission sources

Sources of GHG emissions which are excluded from the assessment (as presented in **Table I**.1 and **Table I**.2) on the basis that they are not expected to form a significant source or are of incidental in nature include:

- Employee travel
- Light construction vehicles (utility vehicles)
- Other construction equipment. The construction process, once materials are delivered to site, would also involve platform lifts and welding / power tools. The energy consumption of this equipment is not forecast to be significant in the context of the other construction emissions, or operational emissions
- Packaging materials for battery components with batteries likely to be delivered fully assembled
- Fuel used by contractors working on site
- Emissions calculated as being fugitive releases of fluorinated gases from switchgear
- Individual components of the BAW other than River Road reconstruction and clearing, on the basis that construction materials are captured in the overall materials quantities and are otherwise not forecast to be significant in the context of the other construction emissions, or operational emissions.

Fuel used by contractors working on site and fugitive releases of fluorinated gases from switchgear are reported by AGLM in its annual National Greenhouse Gas and Energy Reporting (NGER) reporting process.

I.3 Assessment input data

I.3.1 Construction input data

This section presents the methodology used to estimate greenhouse gas emissions associated with construction of the project.

Construction fuel consumption

Construction is expected to take place in three stages, with each stage taking 12 months. Construction involves clearing vegetation and flattening land, installation of a concrete foundation and then import and siting of the battery components. The following assumptions were made in determining fuel used in construction:

- Approximately 20,000 m^3 of spoil was assumed to be moved. Fuel consumption was derived from the Transport Authorities Greenhouse Group *Greenhouse Gas Assessment Workbook for Road Projects* (TAGG 2013) for 'cut to fill'
- It is assumed one 50 t crane is in operation during the construction period, with fuel consumption derived from TAGG 2013 (Crane (Hydraulic) 50 t, Medium application, 300 hours/month)
- The resurfacing of River Road would involve construction materials and fuel. Fuel consumption was derived from TAGG 2013 for construction of 21,000 m^2 of full depth asphalt.

The resulting calculation of fuel consumption was multiplied by the Scope 1 and Scope 3 factor for Stationary Liquid Fuel consumption from the National Greenhouse Accounts (NGA) (Australian Government Department of Industry, Science, Energy and Resources, 2020).

Embedded emissions in construction materials purchases

Greenhouse gas emissions associated with construction materials have been determined using the emission factors provided by the Infrastructure Sustainability Materials Calculator (ISMC) Version 2.0, developed by the ISCA (ISCA, 2019). This calculator evaluates environmental impacts in relation to the use of materials on infrastructure projects and assets. To determine the greenhouse gas emissions from construction materials; material quantity estimates were determined from construction forecasts.

The quantities of construction materials determined for the project is shown in **Table I.3.** These quantities were multiplied against corresponding emission factors as provided in the ISMC for individual materials to determine the resulting Scope 3 greenhouse gas emissions. It should be noted for this part of the assessment that:

- All steel was assumed to be 'reinforcing steel'
- All concrete was assumed to be 32 megapascal (MPa) concrete with 0 % supplementary cementitious material (SCM)
- River Road upgrade was assumed to be resurfaced with full depth asphalt with dimensions 3 km long and 7 m wide (21,000 m^2).

Table I.3 Construction materials input volumes and emission factors

Material	Quantity (t)	Emissions Factor Used	Emissions Factor (tCO_2e / t)
Steel	267	Reinforcement steel mesh, imported	2.73
Concrete (32MPa)	12,000	Concrete 32 MPa 0 % SCM	0.161
Bitumen	676	Bitumen	0.397
Aggregate	26,460	Aggregate	0.0043
Cement	117	Cement	0.984

Embedded emissions in Battery componentry

Greenhouse gas emissions associated with manufacture of the battery componentry have been quantified by using quantities provided in a technology provider Technical Information Sheet for a 150 MWh System and scaling up for a 2,000 MWh system. Emissions factors for battery componentry are much more difficult to source, so published literature has been reviewed to identify suitable emissions factors which have been scaled as required. Battery component quantities and emissions factors are presented in **Table I.4.**

Table I.4 Battery Componentry input quantities and emissions factors

Battery Component	Quantity and Unit of Measure (UoM)	Emissions Factor Source	Emissions Factor (tCO_2e / UoM)
Battery Modules	2,391,693 kWh	Hao et. al., 2017	0.1033
Battery Racks	253 t	Steel - hot rolled powder coated – imported, ISMC	3.42
Inverters	330 t	Allen et. al., 2017	4.08
Transformers - large	600 t	EcoInvent Database v2.2	5.44
Transformers - small	1 t	EcoInvent Database v2.2	5.44
Containers	567 t	Steel - hot rolled powder coated – imported, ISMC	3.42
Cables (m)	7 t	Copper cabling – assumed 32mm2, at 0.371kg / m. Power Cables, Copper conductors, ISMC	2.88

Vegetation clearance

Vegetation is expected to be cleared from the site to enable construction. Loss of vegetation includes loss of the carbon sink and future sequestration potential. The vegetation clearance approach from TAGG 2013 was applied to the site with the following assumptions:

- A ‘Max Bio Class of 4 was applied based on the site location
- 23.6 ha of Exotic Grassland was conservatively assumed to be cleared, which was classified as ‘Grassland’ (at 110 tCO_2e / Ha)
- 18.7 Ha of Woodland was assumed to be cleared which was classified as ‘Open Forest’ (at 521 tCO_2e / Ha).

Note that emissions offsets associated with revegetation have conservatively not been included due to uncertainties over the type of revegetation and the length of time needed to restore the carbon pool. However, the site will be revegetated and a large proportion of the carbon from vegetation clearance would be expected to be sequestered over time.

Fuel combustion from the transport of materials to site

All of the construction materials identified in **Table I**.3 would be transported to site from local sources (steel, bitumen, aggregate and cement) assumed to be Newcastle and concrete assumed to be locally sourced (30 km).

The components listed in **Table I**.4 are assumed to be delivered from China via sea to Newcastle, and then via road to Liddell Power Station.

The emissions factors used to represent sea and road logistics were derived from the ISCA (2019). These provide the GHG emissions from transport of freight per tonne km (i.e. the transport of one tonne by 1 km) (**kg CO_2e / t.km**) which can be multiplied by both the distance travelled and the weight transported to determine the total impact. These are shown in **Table I**.5.

Table I.5 Transport emissions factors

Transport Type	kg CO_2e / t.km
Transport, truck >28t, fleet average	0.0722
Transport, transoceanic freight ship	0.00892

I.3.2 Operation input data

This section identifies the operational input data and methodology used to calculate operational emissions.

The battery is to be installed in three stages making up the total of 2,000 MWh:

- 2021 – 150 MWh
- 2023 – 150 MWh
- 2025 – 1,700 MWh.

Once installed, each stage is assumed to have an operational life of 20 years, meaning the last stage, which will commence operation in 2026, would run to the end of 2045.

Over the 20-year operational life, the battery is expected to degrade in performance such that its capacity is reduced over time. **Table I**.6 shows this expected performance degradation.

Table I.6 Battery performance degradation

Year	Degradation Curve
0 (As new)	100.00 %
1	98.44 %
2	95.52 %
3	92.73 %
4	90.40 %
5	88.09 %
6	86.36 %
7	84.43 %
8	82.48 %
9	80.81 %
10	79.22 %
11	77.69 %
12	75.98 %
13	74.46 %
14	73.11 %

Year	Degradation Curve
15	71.75 %
16	70.47 %
17	69.17 %
18	67.83 %
19	66.43 %
20	65.06 %

The battery is expected to operate 250 cycles per year (full discharge and recharge). Batteries have a typical round trip efficiency of 82 % and the overall system has a round trip efficiency of 71 % meaning that of the energy used to charge the battery, 71 % is sent out when it discharges. The difference between the consumed electrical energy and the sent-out electrical energy are losses in the system which are calculated in **Table I.7** as the operational impact of the system.

Table I.7 Operational energy consumption

Year	Stage 1 (MWh per cycle)	Stage 1 MWh per year	Stage 2 (MWh per cycle)	Stage 2 MWh per year	Stage 3 (MWh per cycle)	Stage 3 MWh per year	Total MWh Output (all stages)	Round Trip Efficiency	Total MWh Input	MWh Consumed (losses in RTE including all kit)
2022	150	37,500	N/A	N/A	N/A	N/A	37,500	0.71	52,817	15,317
2023	148	36,915	N/A	N/A	N/A	N/A	36,915	0.71	51,993	15,078
2024	143	35,820	150	37,500	N/A	N/A	73,320	0.71	103,268	29,948
2025	139	34,774	148	36,915	N/A	N/A	71,689	0.71	100,970	29,281
2026	136	33,900	143	35,820	1,700	425,000	494,720	0.71	696,789	202,069
2027	132	33,034	139	34,774	1,673	418,370	486,178	0.71	684,757	198,580
2028	130	32,385	136	33,900	1,624	405,960	472,245	0.71	665,134	192,889
2029	127	31,661	132	33,034	1,576	394,103	458,798	0.71	646,194	187,396
2030	124	30,930	130	32,385	1,537	384,200	447,515	0.71	630,303	182,788
2031	121	30,300	127	31,661	1,498	374,383	436,344	0.71	614,569	178,225
2032	119	29,708	124	30,930	1,468	367,030	427,668	0.71	602,349	174,681
2033	117	29,134	121	30,300	1,435	358,828	418,261	0.71	589,100	170,839
2034	114	28,493	119	29,708	1,402	350,540	408,740	0.71	575,690	166,950
2035	112	27,923	117	29,134	1,374	343,400	400,456	0.71	564,023	163,567
2036	110	27,416	114	28,493	1,347	336,685	392,594	0.71	552,949	160,355
2037	108	26,906	112	27,923	1,321	330,183	385,011	0.71	542,269	157,258
2038	106	26,426	110	27,416	1,292	322,915	376,758	0.71	530,644	153,887
2039	104	25,939	108	26,906	1,266	316,455	369,300	0.71	520,141	150,841
2040	102	25,436	106	26,426	1,243	310,718	362,580	0.71	510,676	148,096

Year	Stage 1 (MWh per cycle)	Stage 1 MWh per year	Stage 2 (MWh per cycle)	Stage 2 MWh per year	Stage 3 (MWh per cycle)	Stage 3 MWh per year	Total MWh Output (all stages)	Round Trip Efficiency	Total MWh Input	MWh Consumed (losses in RTE including all kit)
2041	100	24,911	104	25,939	1,220	304,938	355,788	0.71	501,109	145,322
2042	N/A	N/A	102	25,436	1,198	299,498	324,934	0.71	457,653	132,719
2043	N/A	N/A	100	24,911	1,176	293,973	318,884	0.71	449,132	130,248
2044	N/A	N/A	N/A	N/A	1,153	288,278	288,278	0.71	406,025	117,747
2045	N/A	N/A	N/A	N/A	1,129	282,328	282,328	0.71	397,644	115,317
Total							**8,126,800**		**11,446,197**	**3,319,397**

The system would be charged by electricity sourced from the NEM in NSW. The greenhouse gas intensity of the NEM in NSW is projected to decrease over time as coal fired generators are retired and lower carbon and renewable energy generation is introduced. **Table I**.8 shows a projection of the NSW NEM greenhouse gas intensity developed by Jacobs (2020) which includes a range of policy, demand, fuel price and technology factors (although it is noted that the modelling does not yet include the recently announced NSW Electricity Infrastructure Roadmap).

Table I.8 NSW NEM greenhouse gas intensity projection (Jacobs modelling)

Year	Greenhouse Gas Intensity (tCO_2e / MWh
2022	0.61
2023	0.59
2024	0.57
2025	0.57
2026	0.57
2027	0.55
2028	0.55
2029	0.55
2030	0.53
2031	0.50
2032	0.45
2033	0.38
2034	0.32
2035	0.26
2036	0.23
2037	0.17
2038	0.13
2039	0.09
2040	0.08
2041	0.08
2042	0.05
2043	0.05
2044	0.03
2045	0.02

No modelling was available for the associated Scope 3 factors (which represent upstream emissions from power generation). These were assumed to decrease at a similar rate to that of the Scope 2 emissions from a starting point of 0.09 tCO_2e / MWh as per the current factor in NGA 2020.