Avoided emissions through use of Vanadium Electrolyte: a case study for the Vecco Critical Minerals Project

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Prepared by:

Katestone Environmental Pty Ltd
ABN 92 097 270 276
Level 4, 154 Melbourne Street, South Brisbane
Queensland, 4101, Australia

www.katestone.global
admin@katestone.com.au
Ph +61 7 3369 3699

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Glossary

Nomenclature	Definition
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalents
t CO_2-e	Tonnes carbon dioxide equivalent
Mt CO_2-e	Million tonnes carbon dioxide equivalent
V_2O_5	Vanadium pentoxide
Abbreviations	**Definition**
AEMO	Australian Energy Market Operator
GHG	Greenhouse gas
GW	Gigawatts
GWh	Gigawatt hours
kW	Kilowatt
kWh	Kilowatt hours
ML	Million litres
MW	Megawatts
MWh	Megawatt hours
NEM	National electricity market
NGER	National Greenhouse gas and Energy Reporting
SMC	Safeguard mechanism credits
VRFB	Vanadium redox flow battery

EXECUTIVE SUMMARY

Katestone Environmental Pty Ltd (Katestone) was commissioned by Vecco Group Pty Ltd (Vecco Group) to explore the avoided emissions that could be accounted for due to vanadium electrolyte produced by the Vecco Critical Minerals Project. Avoided emissions occur because a company's product or service provides a decarbonisation solution, although the savings typically occur outside of a company's value chain (i.e., Scope 3). The measurement of avoided emissions is intended to enable a company to account for the decarbonising impact of their solutions through recognised carbon accounting standards.

Australia is a dominant player in the mining of battery materials, particularly lithium, but to date it is not a significant part of the refining or manufacturing chain. Consequently, the Australian and Queensland Governments are developing battery industry strategies. The proposition that the Vecco Critical Minerals Project will contribute to avoided emissions is based on the cumulative storage capacity of Vanadium Redox Flow batteries (VRFB) using the electrolyte produced by the Project.

The Project will also support the transition to renewable energy generation enabling 2.3 GWh of grid scale battery storage capacity to be manufactured domestically, effectively doubling Australia's current storage capacity and providing 76% of Queensland's projected storage demand by 2030. By 2050 the Project would have supplied enough electrolyte to enable approximately 9.3 GWh of storage capacity.

The four scenarios presented in this report demonstrate that the consequential accounting method (Russell, 2018) can be used to both predict and measure avoided GHG emissions due to vanadium electrolyte, applying current and projected emissions factors which represent the proportion of fossil fuel energy generation to renewable energy generation in the system. Under the scenarios, 27 to 29 MtCO_2-e in avoided emissions could be achieved by 2050 for Queensland, and 23 to 29 MtCO_2-e in avoided emissions achieved for Australia. This is approximately 19-21% of Queensland's current annual emissions and 5-6% of Australia's current annual emissions.

The actual avoided emissions will depend on the rate at which renewable generation replaces fossil fuel generation, i.e., whether State and Commonwealth targets are met, and the consequent change in State and Commonwealth emissions factors. This would be updated as emissions factors are reviewed and published.

Scope 3 emissions are not reported under Australia's National Greenhouse Gas and Energy Reporting (NGER) system, but they are measurable under the GHG Protocol as they can represent a company's greatest opportunity to influence emissions reduction and achieve sustainability-oriented business objectives. There is, however, the potential for an electrolyte producer and a VRFB manufacturer to claim the same avoided Scope 3 emissions.

This may not be an issue when reporting to stakeholders or contributing to Government policy achievements but could become an issue if market instruments such as offset credits required unique claims of ownership. At present, the Safeguards Mechanism will provide tradeable Safeguard Mechanism credit units (SMCs) to companies that reduce their emissions beyond their baselines, but there is no allowance for assisting another entity in a value chain to reduce its emissions.

As a first mover in Queensland, Vecco Group can legitimately stake a claim for a significant role in assisting the Queensland Government in achieving its renewable energy and emissions reduction goals, and its battery industry strategy, through both the mining of V_2O_5 and the production of vanadium electrolyte in the State.

1. INTRODUCTION

Australia is undertaking an energy transformation that will see a reduction in the amount of fossil fuels combusted to produce electricity and an increase in the amount of electricity produced from renewable sources, i.e., solar energy and wind energy. This is expected to contribute to Australia's goals to reduce greenhouse gas (GHG) emissions by 43% from 2005 levels by 2030, and to reach net zero emissions by 2050.

The intermittent nature of renewable energy sources means that significant investment in energy storage systems is required in the development of a Smart Grid. These energy storage systems should ideally provide a range of energy services, including short timescale services such as sag compensation, power smoothing, grid stabilization, and frequency regulation, and longer timescale services such as load leveling, load following, power balancing, peak shaving, and time shifting, while also providing for uninterruptable power supply (Alotto, 2013).

Vecco Group Pty Ltd (Vecco Group) is developing the Vecco Critical Minerals project (the Project) to mine and supply high purity vanadium, high purity alumina, and assorted rare earths, and to produce vanadium electrolyte for the manufacture of Vanadium Redox Flow Batteries (VRFB). A pilot facility with the capacity to produce 2 million litres of vanadium electrolyte per year is in operation in Townsville, and full vanadium electrolyte production of 18 million litres (ML) per annum will be online in mid-2025 to utilise supply of V_2O_5 from the Project. VRFB are likely to be a critical component in the transformation of Australia's electricity network to a smart grid that can match the supply and demand of electricity in real time while minimizing costs and maintaining the stability and reliability of the grid.

In enabling and accelerating the transition to renewable energy and providing load matching services, the presence of VRFB will likely avoid GHG emissions that would otherwise be produced by a hybrid fossil fuel – renewable energy system without storage capacity. Fossil fuel electricity generation is still currently required to provide electricity when intermittent renewable electricity supply does not match demand and the spinning reserve continues to produce GHG emissions without providing electricity to the grid when renewable sources are providing the electricity.

The expected closure of Australia's coal-fired power stations in Australia by 2047 (and the progressive loss of 23 GW of electricity supply) is likely to be matched by an increase in renewable electricity generation and potentially an increase in gas-fired base and peaker plants. Avoided emissions (Russell, 2018) due to the roll out of VRFB could be achieved through contributing to early closure of coal-fired power plants and by reducing the gas-fired baseload or peaker plant capacity required to meet demand.

Katestone Environmental Pty Ltd (Katestone) was commissioned by Vecco Group to explore the avoided emissions that could be accounted for through recognised carbon accounting standards due to vanadium electrolyte produced by the Vecco Critical Minerals Project.

2. VANADIUM REDOX FLOW BATTERIES

VRFBs were patented by Lawrence Thaller at NASA in 1976 (United States Patent No. 3,996,064, 1976). A redox flow battery creates an electric current via ion transfer between two electrolytes that are pumped past a membrane separating an anolyte tank and a catholyte tank. As noted in the patent abstract:

> "There is disclosed an electrically rechargeable REDOX cell or battery system including one or more rebalancing cells. Each rebalancing cell is divided into two chambers by an ion permeable membrane. The first chamber is fed with gaseous hydrogen and a cathode fluid which is circulated through the cathode chamber of the REDOX cell is also passed through the second chamber of the rebalancing cell. Electrochemical reactions take place on the surface of inert electrodes in the first and second chambers to rebalance the electrochemical capacity of the anode and cathode fluids of the REDOX system."

Both electrolytes in a VRFB are vanadium based (unlike in other flow batteries where the electrolytes are different chemicals, e.g., zinc-bromine or chromium-iron), with VO_2^+ and VO^{2+} ions in the anolyte tank and V^{3+} and V^{2+} in the catholyte tank.

VFRB are typically considered for grid storage because they are bulky and heavy. Grid scale batteries have several applications[1], including:

- Arbitrage, i.e., purchasing low-cost off-peak energy and selling it later at a higher price.
- Firming capacity, i.e., providing reliable capacity to meet peak demand.
- Primary frequency response, i.e., providing a very fast response to unpredictable variations in generation and demand.
- Regulation, i.e., providing a fast response to random unpredictable variations in generation and demand.
- Contingency spinning, i.e., providing a fast response to a contingency such as generator failure.

There are several advantages of the VRFB with respect to other battery systems, including other redox flow batteries. These include the non-flammable electrolyte, the capacity for complete discharge without damage, the capacity to charge and discharge for over 10,000 cycles, and because they can respond to a 100% load change in under half a millisecond and can allow overloads up to 400% for 10 seconds (Alotto, 2013).

Redox flow batteries with different chemicals on each side of the membrane suffer irreversible contamination and capacity loss over time due to the diffusion of ions across the membrane. While the diffusion of vanadium ions across the membrane also results in capacity loss over long term operation, it is possible to recycle and restore their capacity in perpetuity because vanadium is the single active element in both the catholyte and anolyte cells (Cao, 2016; Jung, 2023).

The capacity of a VFRB is determined by the amount of electrolyte and area of the electrode, with the voltage of the system determined by the number of cells connected in series. The capacity of lithium batteries, in comparison, can only be increased by increasing the number of parallel connections.

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1 https://www.nrel.gov/docs/fy19osti/74426.pdf

3. RENEWABLE ENERGY GENERATION AND BATTERY STORAGE

3.1 Renewable energy generation and storage targets

Renewable energy generation accounted for just under 40% of Australia's electricity generation in 2022[2] (Table 1), up from 16.9% in 2017. This is expected to grow rapidly as many of the State and Territory Governments, and the Commonwealth Government, have legislated targets for renewable generation and all are investing in this area.

The Australian Energy Market Operator (AEMO) estimates at least 19 GW of storage is required to be installed and operational by 2030 to meet 82% renewables target[3]. The demand for grid stationary storage in Queensland is expected to be about 3 GW by 2030[4]. Currently there is 2.2 GW of storage in the National Electricity Market (NEM).

Australia is a dominant player in the mining of battery materials, particularly lithium, but to date it is not a significant part of the refining or manufacturing chain[5]. Both the Australian Government and Queensland Government are currently consulting on the development of a battery industry strategy[6].

The successful achievement of Queensland's and Australia's emissions reduction and renewable energy targets (Table 1) will depend on the availability of grid-scale batteries that can provide the firming capacity required by the NEM.

Table 1 Renewable energy targets, renewable energy generation in 2022, and current Commonwealth/State emissions factors

Jurisdiction	Generation Targets	Generation (2022)	Storage targets	Current Scope 2 and Scope 3 emissions factor kg CO_2-e/kWh
Queensland	50% by 2030 70% by 2032 80% by 2035	22.6%	Strategy to be developed	0.73 and 0.15
New South Wales	No target	30.7%	2 GW by 2030	0.73 and 0.06
Victoria	40% by 2025 50% by 2030	36.8%	2.6 GW by 2030 6.3 GW by 2035	0.85 and 0.07
South Australia	100% by 2030 500% by 2050	71.5%	No target	0.25 and 0.08

[2] https://assets.cleanenergycouncil.org.au/documents/Clean-Energy-Australia-Report-2023.pdf
[3] https://smartenergy.org.au/wp-content/uploads/2022/11/Unleashing-Renewable-Energy-Storage_1_DIGITAL-1.pdf
[4] https://www.statedevelopment.qld.gov.au/__data/assets/pdf_file/0029/78581/queensland-batteries-discussion-paper.pdf
[5] https://fbicrc.com.au/wp-content/uploads/2021/06/Future-Charge-Report-Final.pdf
[6] https://storage.googleapis.com/converlens-au-industry/industry/p/prj21a171171876878840250/public_assets/national-battery-strategy-issues-paper.pdf

Jurisdiction	Generation Targets	Generation (2022)	Storage targets	Current Scope 2 and Scope 3 emissions factor kg CO_2-e/kWh
Western Australia	No target	35.2%	No target	0.51 and 0.04
Tasmania	150% by 2030 200% by 2040	99.1%	No target	0.17 and 0.01
Australian Capital Territory	100%	100%	No target	0.73 and 0.06
Northern Territory	50% by 2030	< 10%	No target	0.54 and 0.07
Australia	82% by 2030	35.9%	No target	0.68 and 0.09

3.2 Emissions Factors

Emission factors are used to convert the amount of electricity consumed by a purchaser, e.g., kWh, into its emissions equivalent in tCO_2-e. State, Territory, and Commonwealth emissions factors (Table 1) are based on the amount of fossil fuels combusted to produce electricity (Scope 2) and the amount of electricity lost during distribution (Scope 3) within the grid of those jurisdictions. Queensland's current emission factor for electricity production and distribution (0.73 and 0.15 kg CO_2-e/kWh)[7] (Table 1) is higher than South Australia (0.25 and 0.08 kg CO_2-e/kWh), for example, because of the amount of electricity produced by coal or gas in Queensland and because of its extensive grid network. Grid scale batteries are a key option for reducing both emissions and transmission losses, amongst other applications[8].

3.3 Avoided Emissions

Avoided emissions are emissions savings that occur outside of a company's value chain (Scope 3), but that occur because the company's product or service provides a decarbonisation solution. Their measurement is intended to enable a company to account for the decarbonising impact of their solutions through recognised carbon accounting standards. It is possible that multiple entities in a value chain may claim the same Scope 3 emissions reduction or avoidance; double counting becomes an issue if unique claims are made on carbon credits or other market instruments. A rigorous framework has been developed and the methods are currently in development (Russell, 2018; WBCSD, 2023).

There are two possible approaches, attributional accounting, where all the GHG emissions associated with the production of a good or service are measured and compared, and consequential accounting, where the system wide reduction in emissions due to that good or service are measured. Attributional accounting applies a life cycle assessment to determine whether a company's product or service produces fewer life cycle GHG emissions than a similar (reference) good or service that provides an equivalent function. It is a static inventory of absolute emissions and removals. Consequential accounting applies a Policy and Action Standard, which estimates comparative impacts by subtracting emissions in the policy scenario from those of the baseline scenario, e.g., business as usual.

[7] https://www.dcceew.gov.au/sites/default/files/documents/national-greenhouse-accounts-factors-2022.pdf
[8] https://www.nrel.gov/docs/fy19osti/74426.pdf

This assessment will apply consequential accounting, as the focus of the Project is to supply vanadium electrolyte for VRFB manufacture and contribute to the transition of Australia's electricity sector to renewable sources of energy.

4. ASSESSING AVOIDED EMISSIONS

WBCSD (2023) proposes three gates or thresholds for ensuring the eligibility of avoided emissions claims. These are:

- Climate action credibility: the company has a scientific evidence-based strategy and targets for Scope 1, Scope 2, and Scope 3 emissions reduction, and transparently reports on progress on a regular basis
- Climate science alignment: the solution (or end-solution of the intermediary solution) has real mitigation potential and is not applied to activities associated with the production or use of fossil fuels.
- Contribution legitimacy: The solution has a direct and significant decarbonising impact.

Vecco Group has quantified the likely Scope 1 and Scope 2 emissions associated with the mining operations[9], is considering options for Scope 3 emissions reduction, and has developed a decarbonisation plan[10] to progressively reduce the total emissions and emissions intensity of production and increase sequestration of atmospheric carbon. The proposition that the Vecco Critical Minerals Project will contribute to avoided emissions is based on the cumulative storage capacity of VRFB using the electrolyte produced by the Project.

4.1 Approach

The emissions avoided because of the vanadium electrolyte are calculated as a function of:

- The cumulative storage capacity in the electrolyte per year
- The current and projected emissions factor for Queensland and Australia for the life of mine (to 2050).

The pilot facility has the capacity to produce 2 million litres (ML) of vanadium electrolyte per year with V_2O_5 imported from South Africa, and full vanadium electrolyte production of 18 ML per annum will be online in mid-2025 to utilise the supply of V_2O_5 from the Project.

At capacity, the Townsville plant will produce enough electrolyte annually to provide 350 MWh of energy storage capacity per cycle, i.e., 127,750,000 kWh/y, assuming one cycle per day.

Two Queensland scenarios are presented (Figure 1) where:

1. Queensland meets its renewable energy targets, and the emission factor shifts from 0.73 and 0.15 kg CO_2-e/kWh (Table 1) to 0.5 and 0.1 kg CO_2-e/kWh in 2031, 0.25 and 0.08 kg CO_2-e/kWh in 2033, and 0.2 and 0.08 kg CO_2-e/kWh in 2036.
2. Queensland is delayed in meeting its renewable energy targets, and the emissions factor shifts to 0.5 and 0.1 kg CO_2-e/kWh in 2031 (Table 1), 0.25 and 0.08 kg CO_2-e/kWh in 2036, and 0.2 and 0.08 kg CO_2-e/kWh in 2041.

Two Australian scenarios are also presented (Figure 1) where:

1. Australia meets its renewable energy targets, and the emissions factor shifts from 0.68 kg CO_2-e/kWh and 0.09 kg CO_2-e/kWh (Table 1) to 0.2 kg CO_2-e/kWh and 0.09 kg CO_2-e/kWh in 2031.
2. Australia fails to meet its renewable energy targets, and the emissions factor shifts from 0.68 kg CO_2-e/kWh and 0.09 kg CO_2-e/kWh (Table 1) to 0.5 kg CO_2-e/kWh and 0.09 kg CO_2-e/kWh in 2031, and 0.2 kg CO_2-e/kWh and 0.09 kg CO_2-e/kWh in 2041

[9] Trinity Consultants Australia (2023). Debella Critical Minerals Project: Air Quality Assessment. Unpublished report to Vecco Group Pty Ltd.

[10] Katestone Environmental (2023). Vecco Critical Minerals Project Decarbonisation Plan. Unpublished report to Vecco Group Pty Ltd.

4.2 Results

By 2030, the Vecco Critical Minerals Project will supply enough electrolyte to enable 2.3 GWh of grid scale battery storage capacity, doubling Australia's current capacity and providing 76% of Queensland's projected demand[11]. By 2050 the Project will supply enough electrolyte to enable 9.3 GW of storage capacity.

Avoided emissions will increase as 350 MWh of storage is added per annum. Under the four scenarios, this will result in 27 to 29 $MtCO_2$-e in avoided emissions by 2050 for Queensland, and 23 to 29 $MtCO_2$-e in avoided emissions for Australia (Figure 1). This is approximately 19-21% of Queensland's current annual emissions and approximately 5-6% of Australia's current emissions. The actual avoided emissions will depend on the rate at which renewable generation replaces fossil fuel generation, i.e., whether State and Commonwealth targets are met, and the consequent change in State and Commonwealth emission factors.

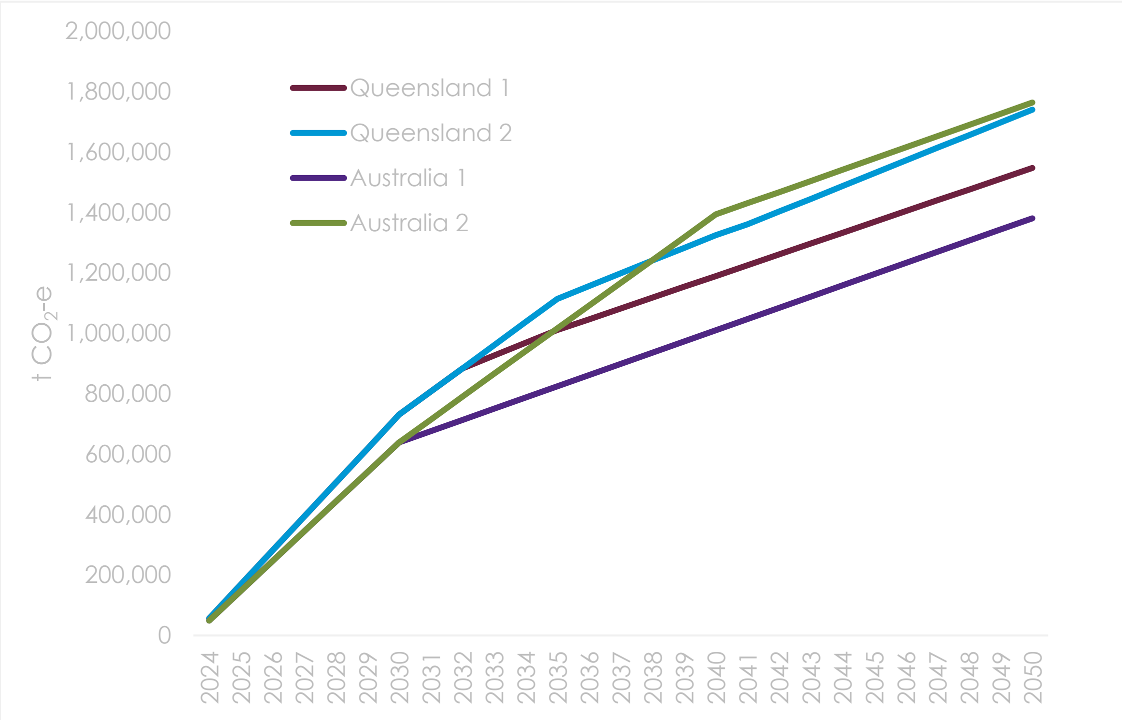

Figure 1 **Modelled cumulative avoided emissions (t CO_2-e) over the life of the Project**

11 https://www.statedevelopment.qld.gov.au/__data/assets/pdf_file/0029/78581/queensland-batteries-discussion-paper.pdf

5. DISCUSSION AND CONCLUSION

Katestone Environmental Pty Ltd (Katestone) was commissioned by Vecco Group Pty Ltd (Vecco Group) to explore the avoided emissions that could be accounted for due to vanadium electrolyte produced by the Vecco Critical Minerals Project. Avoided emissions occur because a company's product or service provides a decarbonisation solution, although the savings typically occur outside of a company's value chain (i.e., Scope 3). The measurement of avoided emissions is intended to enable a company to account for the decarbonising impact of their solutions through recognised carbon accounting standards.

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The Project will also support the transition to renewable energy generation enabling 2.3 GWh of grid scale battery storage capacity to be manufactured domestically, effectively doubling Australia's current storage capacity and providing 76% of Queensland's projected storage demand by 2030. By 2050 the Project would have supplied enough electrolyte to enable approximately 9.3 GW of storage capacity.

The four scenarios presented in this report demonstrate that the consequential accounting method (Russell, 2018) can be used to both predict and measure avoided GHG emissions due to vanadium electrolyte, applying current and projected emission factors, which represent the proportion of fossil fuel energy generation to renewable energy generation in the system. Under the scenarios, 27 to 29 $MtCO_2$-e in avoided emissions could be achieved by 2050 for Queensland, and 23 to 29 $MtCO_2$-e in avoided emissions achieved for Australia, based on relative emissions factors. This is approximately 19-21% of Queensland's current annual emissions and approximately 5-6% of Australia's current annual emissions.

The actual avoided emissions will depend on the rate at which renewable generation replaces fossil fuel generation, i.e., whether State and Commonwealth targets are met, and the consequent change in State and Commonwealth emissions factors. This would be updated as emissions factors are reviewed and published.

Scope 3 emissions are not reported under Australia's National Greenhouse Gas and Energy Reporting (NGER) system, but they are measurable under the GHG Protocol as they can represent a company's greatest opportunity to influence emissions reduction and achieve sustainability-oriented business objectives. There is, however, the potential for an electrolyte producer and a VRFB manufacturer to claim the same avoided Scope 3 emissions, causing confusion.

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As a first mover in Queensland, Vecco Group can legitimately stake a claim for a significant role in assisting the Queensland Government in achieving its renewable energy and emissions reduction goals, and its battery industry strategy, through both the mining of V_2O_5 and the production of vanadium electrolyte in the State.

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