SOUTH32
Worsley Alumina

GREENHOUSE GAS MANAGEMENT PLAN

SOUTH32 WORSLEY ALUMINA

WORSLEY MINE EXPANSION REVISED PROPOSAL EPA ASSESSMENT NO. 2216

MAY 2022

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1 SUMMARY

This draft Greenhouse Gas Management Plan (GHGMP) has been prepared in accordance with Part IV of the *Environmental Protection Act 1986* (WA) (EP Act) and associated guidance from the Environmental Protection Authority (EPA), to support the assessment, approval and implementation of the proposed Worsley Mine Expansion (the Revised Proposal) which was referred to the EPA for assessment on 5 April 2019. Table 1 summarises the context and purpose of the GHGMP in line with the EPA's draft *Content of a Greenhouse Gas Management Plan* (EPA, 2020a).

Table 1: Summary of the Proposal and Key Provisions

Proposal Name	**Worsley Mine Expansion (Revised Proposal)**
Proponent Name	South32 Worsley Alumina Pty Ltd (Worsley Alumina)
Purpose of the GHGMP	To support reductions in GHG emissions from the Revised Proposal to as low as reasonably practicable and contribute to Western Australian and South32's respective net zero GHG emissions by 2050 goals.
Objectives of the GHGMP	The objectives of this GHGMP are to: • Support the assessment, approval and implementation of the Revised Proposal under Part IV of the EP Act in accordance with relevant Western Australian Government policies and guidelines including: – *Greenhouse Gas Emissions Policy for Major Projects* (DWER, 2019); – *Western Australian Climate Policy* (DWER, 2020); – *GHG Emissions Environmental Factor Guideline* (EPA, 2020b); – *Instructions on how to prepare EP Act Part IV Environmental Management Plans* (EPA, 2017); and – *Content of a Greenhouse Gas Management Plan* (EPA, 2020a; draft). • Provide for ongoing GHG emission reductions at Worsley Alumina over the life of the Revised Proposal and beyond, consistent with South32's group-wide goal to reach net zero operational emissions by 2050 and the Western Australian Climate Policy aspiration of net zero emissions by 2050; • Set regular interim emission reduction targets over the life of the Revised Proposal that drive incremental reductions in net operational emissions (i.e. Scope 1 and 2 emissions), supported by regular review and evaluation reporting on a minimum 5-yearly basis; • Outline current and future strategies and activities that demonstrate all reasonable and practicable measures are considered and applied in accordance with the mitigation hierarchy to reduce operational emissions from the Revised Proposal in line with the interim targets; • Provide for the adoption of best practice design, technology and management to mitigate GHG emissions over the life of the Revised Proposal, including adaptive management to respond to current uncertainties and future developments in technology, markets and government policy; and • Take account of impacts from the energy transition and seek to realise new opportunities including jobs, technologies and emerging industries for affected people, communities and businesses.
Ministerial Statement	A new Ministerial Statement is proposed to be issued with associated conditions, that will apply to the Revised Proposal. Worsley Alumina currently operates under Ministerial Statement No. 719 which was issued by the Minister for the Environment on 13 April 2006 and includes condition 6 Greenhouse Gas abatement
Condition Clauses	If the Revised Proposal is approved and a new Ministerial Statement issued, this draft GHGMP will be updated to reflect the associated conditions.
Key Environmental Factor and Objective	EPA factor: Greenhouse Gas Emissions EPA objective: *To reduce net greenhouse gas emissions in order to minimise the risk of environmental harm associated with climate change* (EPA, 2020b).
Key Provisions and Outcomes in the GHGMP	To deliver a reduction in GHG emissions at Worsley Alumina through a transparent, responsible and reasonable approach using the following key provisions: • Establish interim emission reduction targets that guide incremental reductions in net operational emissions (i.e. Scope 1 and 2 emissions) over the life of the Revised Proposal;

	• Build on existing studies and emission reduction activities to develop and implement where reasonably practicable a pipeline of projects that support the delivery of the interim targets in accordance with the mitigation hierarchy, focusing on three key themes: – Energy Efficiency – Fuel Switching – Long-term Studies and Future Technology; • Utilising an adaptive management approach to optimise the delivery of the proposed and future management actions; • Committing to annual review of this GHGMP and five yearly review and revision to monitor and improve the effectiveness of emission reduction measures, with revised versions of the GHGMP to be approved by DWER; • Participating in just transition planning in collaboration with multiple stakeholders to support a responsible and fair energy transition; • Working with customers and industry partners to address value chain emissions; and • Transparent and regular reporting of performance against regulatory (e.g. *National Greenhouse and Energy Reporting Act 2007* (NGER Act) and voluntary schemes.
Proposed Construction Date	NA due to Revised Proposal enabling continuation of existing operations.
EMP pre-construction	NA. Worsley Alumina currently has in place an approved GHGMP (as per condition 6-1 of MS 719). This version represents an update to the current plan to reflect the proposed changes to the proposal and updated greenhouse gas policy and guidelines.

2 INTRODUCTION

This draft GHGMP has been prepared by Worsley Alumina to support the assessment, approval and implementation of the proposed Worsley Mine Expansion (the Revised Proposal – Refer to Section 3.1), referred to the EPA for assessment under Section 38 of the EP Act on 5 April 2019.

Amongst other matters, this GHGMP details Worsley Alumina's approach to the management and reduction of GHG emissions associated with the Worsley Alumina Project at a whole of operations level inclusive of the Boddington Bauxite Mine (BBM) and the Worsley Alumina Refinery (the Refinery), establishes interim emission reduction targets and demonstrates that all reasonable and practicable measures have been applied to avoid, reduce and offset the GHG emissions associated with the Revised Proposal.

The GHGMP also describes Worsley Alumina's contribution towards the Western Australian Government's aspiration of net zero emissions by 2050, which aligns with South32's group level emissions reduction target to halve operational emissions across the group by 2035 and net zero operational emissions by 2050 goal.

The contents of this GHGMP have also been developed in accordance with EPA guidance *Content of a Greenhouse Gas Management Plan* (EPA, 2020a; draft), which was in draft status at the time of preparation of this GHGMP, and with reference to the *Greenhouse Gas Emissions Policy for Major Projects* (DWER, 2019), *GHG Emissions Environmental Factor Guideline* (EPA, 2020b), and *Instructions on how to prepare EP Act Part IV Environmental Management Plans* (EPA, 2017).

3 CONTEXT, SCOPE AND RATIONALE

3.1 DESCRIPTION OF THE WORSLEY ALUMINA PROJECT AND THE REVISED PROPOSAL

The Worsley Alumina Project is comprised of the Boddington Bauxite Mine (BBM) and the Refinery and has been operating since 1984. The BBM is located 130 km southeast of Perth, Western Australia, and the Refinery is located 47 km south-west of the BBM. The Worsley Alumina Project has been subject to a number of incremental expansions of mining areas and increases in the overall production rate at the Refinery. The Revised Proposal for the Worsley Mine Expansion includes the continuation of existing operations at the BBM, Refinery and overland bauxite conveyor as approved under existing operating approvals, while the assessment component of the Revised Proposal is based on expansion activities being undertaken in three development envelopes, namely the Worsley Mine Development Envelope, Bauxite Transport Corridor and Contingency Bauxite Mine

Envelope. Therefore, this GHGMP accounts for the Worsley Alumina operations holistically and will remain an adaptive management plan over time through periodic reviews and updates.

The indicative life of the Revised Proposal is approximately 15 years. However, the already established Worsley Alumina operations will continue beyond 2050 under existing authorised extents (i.e. approved extended mining areas).

The Revised Proposal will allow operations to sustain the currently approved bauxite mining rate of 18.8 Mtpa (dry), whilst the alumina production rate will remain unchanged at 4.7 Mtpa. Accordingly, as a starting point, the GHG emissions associated with the Revised Proposal will not exceed the current authorised net emission limit of 3.75 Mtpa CO_2-e under MS719 and will be used as a baseline to calculate proposed interim reduction targets and performance against those targets (see Section 4.1.1).

The continued operation of the Worsley Mine Expansion will maintain significant economic benefits and stable employment opportunities for individuals and businesses in the South West Region and will provide on-going community and social benefits to the regions of the Peel and South West. Beyond this regional value, the alumina produced at Worsley Alumina is used to produce aluminium, which South32 considers will play a key role in the transition to a low-carbon, global economy, due to its wide-ranging applications in transportation, construction, packaging and consumer goods.

3.2 GHG EMISSION SOURCES

The largest source of GHG emissions is associated with the Refinery operations due to the energy demand to generate steam for the Bayer alumina refining process. Process steam is currently generated from a mix of coal fired boilers and a multi-fuel co-generation steam and power generation plants (MFC's). Electricity is generated as a by-product using the existing onsite power stations, with electricity either consumed at the BBM and the Refinery or exported to the grid.

In FY21, Worsley Alumina's net operational GHG emissions [1] totalled 3.74 Mt CO_2-e. If Worsley Alumina were to continue to operate under the existing authorised limits, sustain its existing mining and production rates and took no further action to reduce its GHG emissions, total Scope 1 and Scope 2 emissions would be in the order of 56.1 Mt CO_2-e over the life of the Revised Proposal (i.e. 3.74 Mt CO_2-e per year over the indicative 15 year period).

Sections 3.2.1 and 3.2.2 provide a detailed breakdown of the material emission sources at the BBM and Refinery respectively.

GHG emission forecasts are maintained within the Worsley Alumina Life of Operations Plan (LoOP), which contains identified production variables and associated emissions intensities. The maintenance and review of the LoOP helps to determine and design the mitigation measures identified in Section 4.1.2, which are reviewed and updated on a regular basis.

3.2.1 BBM – Operational GHG Emissions

In FY21, operational GHG emissions from the BBM were only three per cent of Worsley Alumina's net operational emissions. All of the BBM's emissions are reported as Scope 1 emissions, with the majority of these being attributed to the:

- combustion of coal (plus very minor amount of biomass) at the Refinery to generate electricity for use at the BBM; and
- diesel consumption from use of light and heavy mobile equipment.

Other minor sources of operational GHG emissions (<1%) at the BBM, include:

- diesel consumption for stationary equipment, drill and blast activities, pumps, and lighting towers;
- sulfur hexafluoride (SF6) from switchgear;
- methane emissions from sewerage wastewater;
- clearing of vegetation; and
- methane and nitrous oxide emissions from domestic solid wastes.

Table 2 lists the material operational emission sources for the BBM, FY21 actual emissions and the percentage contribution of each source to the total operational emissions for the BBM and the Refinery.

[1] Net operational emissions include total Scope 1 and 2 emissions (calculated using methodologies and emissions criteria in the NGER Safeguard Mechanism Rule 2015 (Commonwealth of Australia, 2015)), and adjusted to account for the net emissions balance between import and export electricity between the Refinery and the SWIS (and may include electricity supplied through renewable energy power purchase agreements).

Table 2: Net GHG Emissions for the BBM (FY21)

Emissions Source	Emissions (Kt CO_2-e)	% Emissions BBM	% Emissions BBM and Refinery
Scope 1			
Coal (and biomass) combustion – electricity[(a)]	36	36	1
Diesel consumption - transport	62	62	2
Other	1	1	<1
TOTAL SCOPE 1 + SCOPE 2	**99**	**100[(b)]**	**3**

(a) The split for energy consumption between the BBM and the Refinery is based on the amount of steam used in the Refinery and the relative ratio of power consumed at both the Refinery and the BBM.
(b) The sum of the sources vary to total figure due to rounding.

The GHG emissions intensity for the FY21 activities at the BBM is calculated as 0.00564 t CO_2-e/t of bauxite.

Given that the mining rate is not proposed to change, additional emissions generated from the Revised Proposal at the BBM are limited to increased fuel demand of longer haul distances and emissions associated with vegetation clearing and decomposition of cleared vegetation[2] (maximum annual emissions of 15.2 Kt CO2-e) (KASA, 2020). In the context of the Revised Proposal, this increase represents approximately 0.4% in emissions against the total annual emissions of the Revised Proposal (and in the absence of specific emission reduction activities).

3.2.2 Refinery – Operational GHG Emissions

The primary source of carbon emissions at the Refinery is from the combustion of energy coal and natural gas to generate steam for the alumina refining process (digestion and evaporation units) and associated generation of electricity, accounting for approximately 75% of Worsley Alumina's emissions. Natural gas is also consumed for heating in calcination to ~950°C.

The steam is produced at high pressure (>10MPa) which is then reduced to 1300kPa and 450kPa for use in the Refinery. The most efficient method of reducing the steam pressure is through turbines which generate electricity as steam pressure declines, with the electricity then able to be used at the Refinery and BBM. The total electrical power generated is dependent on the total steam demand and the number of steam generation and turbine units online. The majority of electricity generated is consumed by the Refinery and BBM, with any excess (or shortfall) balanced by exporting (or importing) from the South West Interconnect System (SWIS) grid. Diesel consumption for stationary equipment and transport contributes 17,785 t CO2-e / yr (less 1% of emissions at the Refinery).

Scope 2 emissions amount to only a small portion of the operational emissions profile at the Refinery (2%), with electricity imported from the grid restricted to short-periods during maintenance activities and shutdowns. Worsley Alumina's operational emissions are calculated in accordance with NGER, adjusted to account for the net emissions balance between import and export electricity between the Refinery and the SWIS grid, which may include electricity supplied through renewable energy power purchase agreements.

Other minor operational emission sources (<1%) at the Refinery (all Scope 1 emissions), include:

- petrol consumption for transport vehicles;
- stationary combustion of petroleum-based oils and greases, and gaseous fossil fuels;
- hydrofluorocarbons (HFCs) and SF_6 from switchgear;
- methane emissions from sewerage wastewater; and
- methane and nitrous oxide emissions from domestic solid wastes.

Table 3 lists the material operational emission sources for the Refinery, FY21 actual emissions and the percentage contribution of each source to the total operational emissions for the Refinery and the BBM.

[2] Emissions associated with vegetation clearing and decomposition are not reported under NGERs. Estimates exclude sequestration of emissions by mine rehabilitation or reforestation associated with biodiversity objectives.

Table 3: Net GHG Emissions for the Refinery (FY21)

Source	Emissions (Kt CO_2-e)	% Emissions of Refinery	% Emissions of BBM + Refinery
Scope 1			
Coal (and biomass) combustion	2,564	70	69
Gas combustion	976	27	26
Diesel consumption (transport and stationary equipment)	18	<1	<1
Other	<1	<1	<1
Total Scope 1	**3,559**	**98**	**95**
Scope 2			
Refinery electricity (from grid)	80	2	2
Total Scope 2	**80**	**2**	**2**
TOTAL SCOPE 1 + SCOPE 2	**3,639**	**100**	**97**

The GHG emissions intensity for the FY21 activities at the Refinery are calculated as 0.790 t CO_2-e/t alumina product (inclusive of Scope 1 and 2). Note that the annual production rates of alumina for the Revised Proposal are proposed to remain within the currently approved limit of 4.7 Mtpa. Given that the annual alumina production rate is not proposed to change, it is assumed that the GHG emissions associated with the Refinery will remain consistent over the life of the Revised Proposal in the absence of specific emission reduction activities.

3.2.3 Scope 3 – Value Chain Emissions

Worsley Alumina's total Scope 3 emissions were calculated as 15.1 Mt CO_2-e in FY21, in accordance with the methodologies in the GHG Protocol Technical Guidance for Calculating Scope 3 Emissions (World Resources Institute, 2013). It should be noted that the calculated Scope 3 emissions for the Revised Proposal account for South32's downstream ownership of two Aluminium smelters, Hillside Aluminium and Mozal Aluminium, where the alumina product is processed and include a proportional allocation of select Scope 3 categories that apply to South32's group operations (i.e. business travel and commuting employees is calculated at a whole of group level in accordance with the GHG protocol – not at facility level). The most material contributor to Worsley Alumina's Scope 3 emissions relates to processing of sold products making up 97%. This includes processing of alumina to aluminium at non-South32 operated smelters, and aluminium into aluminium ingot / aluminium ingot into aluminium sheet [3].

Worsley Alumina's FY21 Scope 3 emissions are assumed to be representative of the Scope 3 profile over the life of the Revised Proposal and are estimated to be in the order of 226.5 Mt CO_2-e, assuming the current South32 portfolio remains unchanged and in the absence of emission reduction activities at non-South32 operated smelters that process Worsley Alumina's product.

Other Scope 3 categories defined in the GHG Protocol account for only 3% of Scope 3 emissions for the Revised Proposal. These include:

- Purchased good and services;
- Capital goods;
- Fuel and energy-related activities;
- Upstream emissions from purchased electricity;
- Upstream and downstream transport and distribution;
- Business travel and commuting employees; and
- Investments.

[3] Data sources for the processing of sold products included the International Aluminium Institute's 'Life Cycle Inventory Data and Environmental Metrics' report (World Aluminium, 2015), and the European Aluminium Association's 'Environmental Profile Report' (European Aluminium Associations, 2013).

3.3 CONDITION REQUIREMENTS

Worsley Alumina has a current and approved GHGMP as required under Condition 6: Greenhouse Gas Abatement (clauses 6-1 to 6-3) of MS719. Worsley Alumina will continue to implement the applicable requirements of MS719 until a revised and consolidated Ministerial Statement and associated conditions is released as a part of the approval process for the Revised Proposal. It is expected that this draft GHGMP will be amended and then finalised as a part of the approval process.

3.4 RATIONALE AND APPROACH

This section outlines the key information sources and aspects informing the rationale and approach of the management provisions outlined in Section 4. It includes:

- A description of the objectives of the GHGMP and approach;
- Benchmarking against similar facilities;
- Summary of findings from key studies undertaken to date to inform Worsley Alumina's current emission reduction workstreams; and
- Key assumptions and uncertainties.

3.4.1 Management Objectives and Approach

The objectives of this GHGMP are to:

- Support the assessment, approval and implementation of the Revised Proposal under Part IV of the EP Act in accordance with relevant Western Australian Government policies and guidelines including:
    - *Greenhouse Gas Emissions Policy for Major Projects* (DWER, 2019);
    - *Western Australian Climate Policy* (DWER, 2020);
    - *GHG Emissions Environmental Factor Guideline* (EPA, 2020b);
    - *Instructions on how to prepare EP Act Part IV Environmental Management Plans* (EPA, 2017); and
    - *Content of a Greenhouse Gas Management Plan* (EPA, 2020a; draft).
- Provide for ongoing GHG emission reductions at Worsley Alumina over the life of the Revised Proposal and beyond, consistent with South32's goal to reach net zero operational emissions by 2050 and the Western Australian Climate Policy aspiration of net zero emissions by 2050;
- Set regular interim targets that drive incremental reductions in net operational emissions over the life of the Revised Proposal;
- Outline current and future strategies and activities that demonstrate all reasonable and practicable measures are considered and applied in accordance with the mitigation hierarchy to avoid, reduce and offset the Revised Proposal's operational emissions in line with the interim targets;
- Provide for the adoption of best practice design, technology and management to mitigate GHG emissions over the life of the Revised Proposal, including adaptive management to respond to current uncertainties and future developments in technology, markets and government policy;
- Take account of impacts from the energy transition and seek to realise new opportunities including jobs, technologies and emerging industries for affected people, communities and businesses; and
- Set out regular review provisions and prepare a revised GHGMP at least every five years.

A key challenge for decarbonising Worsley Alumina is developing feasible solutions for generating process steam at scale for refining bauxite to alumina which requires a significant amount of thermal energy, noting this cannot easily be met by the large-scale deployment of renewable energy sources that do not generate thermal energy directly, such as solar PV and wind. Section 4.1.2.3.1 provides further details on emission reduction studies and projects, which are focused on addressing these primary emission sources by reducing energy consumption and transitioning our energy sources to lower carbon alternatives.

These challenges are compounded by the need to integrate feasible solutions with the operation of the existing, established infrastructure at the Refinery which was designed and constructed over 40 years ago. Unlike some other 'newer' brownfield projects, where the materials used may allow them to more easily switch out the current infrastructure and make use of the

cleaner mechanisms that are available in today's markets, the retrofitting of vintage infrastructure presents a series of unique challenges that require Worsley Alumina to think differently about how to efficiently reduce and transition our energy supply.

3.4.2 Benchmarking

In recognition that no changes to the alumina production rate associated with the Refinery are proposed with the implementation of the Revised Proposal, benchmarking is discussed in the context of:

- providing discrete discussion as related to the continued operation and expansion of mining activities at the BBM; and
- continued operation of Refinery activities.

The outcomes of the benchmarking assessment are summarised below. The full report prepared by Ramboll (2020) on the benchmarking assessment is provided as Appendix A.

3.4.2.1 Boddington Bauxite Mine

Australia is the world's largest producer of bauxite, with five mines supplying around 30% of global production. These include the BBM, Rio Tinto's Gove (Northern Territory) and Weipa (Queensland), and Alcoa's Huntly (WA) and Willowdale (WA) (Australian Aluminium Council, 2020a). As bauxite mining consumes a relatively small amount of energy compared to other parts of the aluminium life cycle, limited data is available on the total GHG emissions and emissions intensities from the Australian bauxite mining sector (Ramboll, 2020).

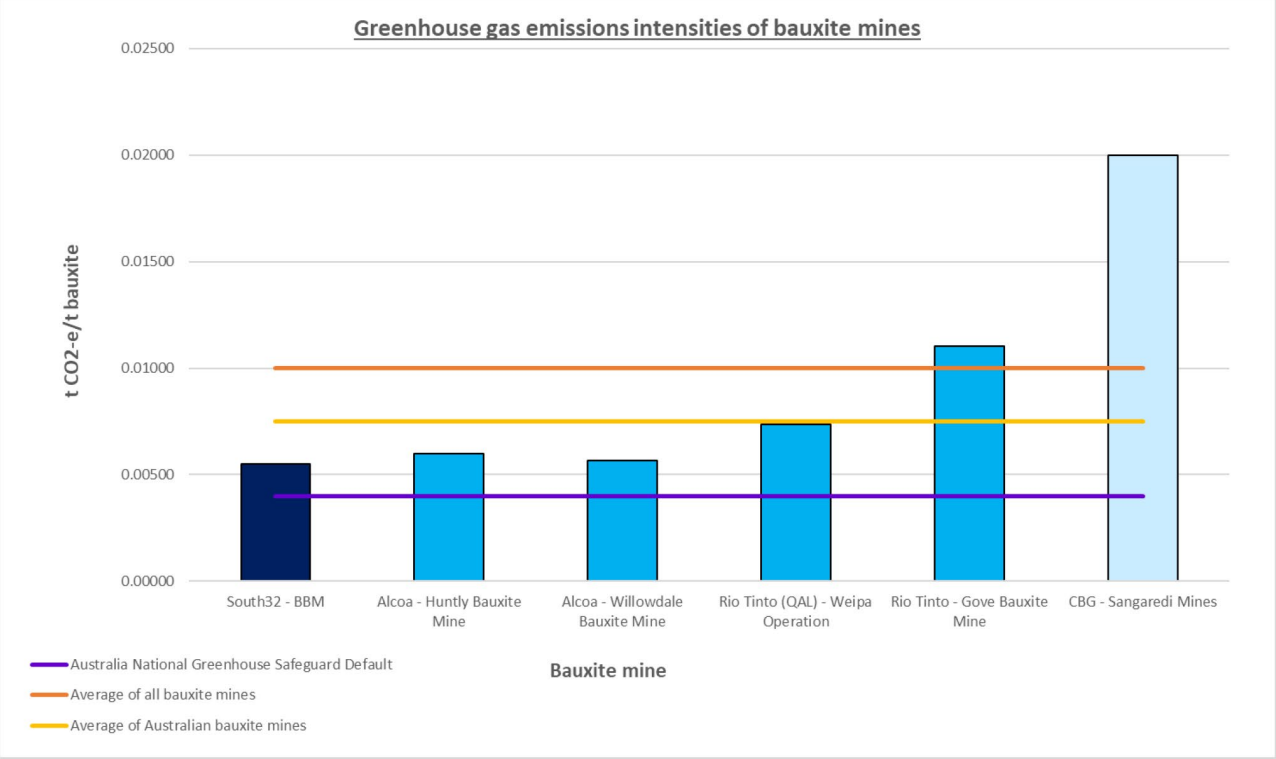
Information compiled for the purposes of benchmarking the BBM includes average emissions intensities for the Australian bauxite mines identified above and one international bauxite mine; CBG's Sangaredi Mines (Guinea). These were selected based on availability of public data and with selection of comparable operations producing a similar product to Worsley Bauxite-Alumina, both within Australia and overseas. Average emissions intensities (Scope 1) were compared against:

- the Commonwealth Safeguard default emissions intensity for bauxite mining (0.00401 t CO_2-e/t bauxite), as outlined in the Safeguard Mechanism document: Prescribed production variables and default emissions intensities (DISER, 2020);
- the calculated average of Australian benchmarked bauxite mines identified above (0.00751 t CO_2-e/t bauxite); and
- the calculated average of all benchmarked bauxite mines identified above (0.01001 t CO_2-e/t bauxite) (Ramboll, 2020).

The results of the benchmarking assessment for the BBM are shown in Figure 1 and indicate that the GHG emissions intensity for the BBM (0.00552 t CO_2-e/t bauxite, Scope 1 forecast for FY22[4]) is the lowest among the benchmarked examples. The BBM is approximately 46% lower than the average of all benchmarked bauxite mines identified above and approximately 36% lower than the average of the benchmarked Australian bauxite mines. The emissions intensity at the BBM is comparable to the average emissions intensity at the neighbouring Alcoa Willowdale bauxite mine (0.006 t CO_2-e/t bauxite). This is assumed to be related to haul distances and proximity to crusher and conveyor infrastructure, of comparable mining operations.

As diesel consumption for transport provides the majority of GHG emissions from the BBM (See Table 2), it is considered that efforts to reduce GHG emissions from mining and mineral processing should focus on loading and haulage activities (KASA, 2020), albeit these contribute less than 2% of the overall emissions of the BBM and the Refinery. Coal combustion for electricity is also a major contributor to the BBM emissions profile, however, the coal combustion activity occurs using infrastructure located at the Refinery. Efforts to reduce GHG emissions associated with coal combustion are discussed with reference to the Refinery throughout this GHGMP.

[4] FY22 was selected by Ramboll for the benchmarking year as it has the highest production forecast production rate and is considered a conservative approach for the assessment. It is noted that the FY21 GHG emissions intensity at BBM was 0.00564 t CO_2-e/t bauxite, and is comparable with the FY22 benchmark used by Ramboll.



Note: Averages shown in orange and red relate to the operations included in the benchmarking.

Figure 1: GHG emissions intensities for the BBM and benchmarked facilities (Source: Ramboll, 2020)

3.4.2.2 Refinery

China is the world's leading producer of alumina, producing an estimated 71,284 kt of alumina in 2019, which equates to approximately 54% of global production. Australia is the second highest producer with an estimated 20,491 kt of alumina produced in 2019, which equates to approximately 15% of global production (International Aluminium Institute, 2020). There are six alumina refineries operating in Australia, namely the Worsley Alumina Refinery, Alcoa's Kwinana, Pinjarra and Wagerup refineries (WA), and Rio Tinto's Queensland Alumina Ltd and Yarwun refineries (Queensland) (Australian Aluminium Council, 2020b).

Information compiled for the purposes of benchmarking the Worsley Alumina Refinery includes average emissions intensities for the Australian refineries identified above and seven international alumina refineries namely Hydro's Alunorte (Brazil), Alcoa's San Ciprian Alumina (Spain) and Point Comfort Alumina (United States), RUSAL's Aughinish Alumina (Ireland) and Friguia Alumina (Guinea), Rio Tinto's Jonquiere (Vaudreuil) (Canada), and Noranda's Alumina refinery (United States). These were selected based on availability of public data. Average emissions intensities (Scope 1) were compared against:

- the Commonwealth Safeguard default emissions intensity for alumina refineries (0.545 t CO_2-e/t alumina and equivalent tonne of alumina trihydrate product) as outlined in the Safeguard Mechanism document: Prescribed production variables and default emissions intensities (DISER, 2020),
- the calculated average of Australian benchmarked alumina refineries identified above (0.663 t CO_2-e/t) (Ramboll, 2020); and
- the calculated average of all benchmarked alumina refineries identified above (0.685 t CO_2-e/t) (Ramboll, 2020).

The results of the benchmarking assessment for the Worsley Alumina Refinery are shown in Figure 2. A full summary of all facilities data used to inform the benchmarking study are provided in Appendix A (and specifically Appendix 1 of Ramboll, 2020). The results show that the GHG emissions intensity for the Worsley Alumina Refinery (0.786 t CO_2-e/t alumina, Scope 1 forecast for FY22) is 13% higher than the average emissions intensities for all benchmarked alumina refineries, 16% higher than benchmarked Australian refineries and 31% higher than the Safeguard default value.

Of the benchmarked refineries, the lowest emissions intensity is at Rio Tinto Jonquiere (Vaudreuil) in Canada, which utilises hydroelectric power. The primary fuel source used in Australia is gas (68%), seconded by coal (23%). The Worsley Alumina Refinery currently uses coal as its primary fuel source, as do the RUSAL refineries in Ireland and Guinea. When compared with facilities using similar fuel types (as the most accurate indicator of a like-for-like comparison, with the information available), the Worsley Alumina Refinery is considered to have one of the lowest GHG emissions intensities (Ramboll, 2020). It is recognised that the type of bauxite ore (e.g. gibbsite, boehmite or diaspore) determines if high temperature digestion is required and consequently could have a significant influence on the energy efficiency of that facility, which is relevant when comparing refineries.

While facility specific data was not able to be obtained from refineries in China and Russia, it is understood that coal is also used extensively at these locations and is considered to be one of the main drivers of the elevated global average (Ramboll, 2020). The inclusion of China and Russia drives the global average up to 1.345 t CO_2-e/t alumina, which Worsley Alumina is well under (by 41%). The use of thermal coal as a primary energy source elevates Worsley Alumina's emissions intensity, although it is noted that Worsley Alumina's energy intensity (10.5-10.6 GJ/t alumina) is lower than the global (11.4 GJ/t alumina) and Oceania (10.7 GJ/t alumina) average for alumina refineries (cite IEA reference, 2018), demonstrate that Worsley Alumina is well positioned to improve its relative position against benchmarked refineries in a scenario where it is able to transition its current thermal coal consumption for the required process steam, to a lower carbon alternative.

The outcomes of the benchmarking study also show that one of the greatest opportunities to reduce GHG emissions from the Refinery is through fuel switching. More information on fuel switching and other decarbonisation initiatives being considered for the Refinery are included in Section 4.1.2.

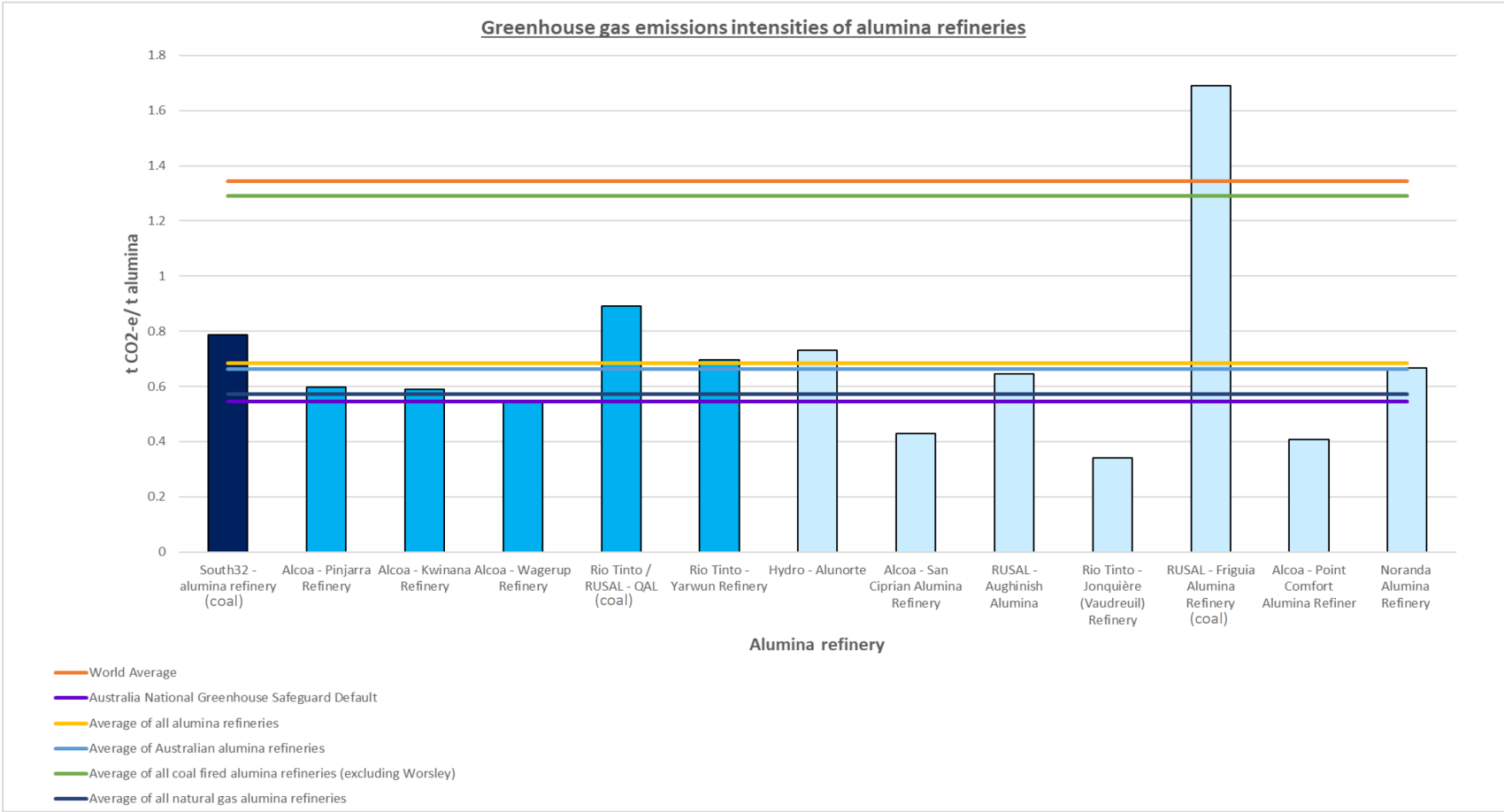


Figure 2: GHG emissions intensities for the Worsley Alumina Refinery and benchmarked facilities *(Source: Ramboll, 2020)*

3.4.3 Study Findings

Table 4 presents the findings of key studies that have been undertaken that have informed the current approach relating to this GHGMP. Many of the studies were undertaken as part of Worsley Alumina's decarbonisation program and continue to inform Worsley Alumina's current study and projects portfolio that are outlined in Section 4.1.2 of this GHGMP.

Table 4: Summary of GHG Studies to Date

Study	Description of Findings
Mud Washing (Active)	A study is underway to investigate the technical and commercial feasibility of the addition of new high efficiency washers to reduce the amount of water required to wash the mud, which will in turn reduce the amount of evaporation which is required and therefore reduce the need for coal fired steam requirements. More information on the assessment is provided in Section 4.1.2.1.1.
Coal to gas conversion (Active)	A coal to gas conversion study is underway to evaluate the technical and commercial feasibility of displacing coal as the primary fuel source to the coal and multi-fuel cogeneration boilers on site. More information on the feasibility assessment is provided in Section 4.1.2.2.1.
Worsley Alumina Environmental Constraints Study (2021)	This study reviewed CY2020 performance, energy intensity, carbon emissions, particulate emissions, flue gas emissions and residue deposition to support Worsley Alumina's future planning and to ensure Worsley Alumina complies with the existing conditions under MS719. Amongst other matters, the study confirmed that energy efficiency and coal to gas studies currently underway should continue to be progressed.
Beyond Capability Project (2021)	The Beyond Capability Project is a study into debottlenecking facilities at the Refinery in order to increase the Refinery throughput up to 4.7 Mtpa and improve the Refinery energy intensity. The Beyond Capability Project identified 40+ facilities that have potential to be de-bottlenecked, which are currently under further individual investigation, including potential energy efficiency projects.
Worsley Mine Expansion GHG Assessment (2020)	Emissions sources and GHG intensity were calculated as related to the BBM only (KASA, 2020). In comparing BBM operations to other bauxite mines, it was identified that the BBM has a comparatively low emissions intensity. It also identified that for the BBM, addressing loading and haulage activities are likely to provide the greatest opportunity at the BBM for emissions reductions (See Section 3.3.2.1).
Decarbonisation Concept Study (2019)	The Decarbonisation Concept Study identified over 80 potential decarbonisation initiatives through planning and assessment work for the Refinery. The initiatives identified through the study have informed the Worsley Alumina portfolio of current studies and projects that are the focus for delivering the emission reduction targets outlined in this GHGMP. More information on the Decarbonisation Concept Study and subsequent initiative assessments is provided in Section 4.1.2.
Concentrated Solar Thermal (2017)	Pre-feasibility assessment to investigate the use of concentrated solar thermal for the Refinery operations. This included a review of various technologies on the market, that could potentially be employed by Worsley Alumina. Whilst the current technologies appear to be able to provide a moderate level of stability, the maintenance and the scale of the use of any single technology is not currently conducive to the requirements of the Refinery operations. This is discussed further in Section 4.2.2.
Geothermal Initiative Concept Level Assessment (2008)	A concept level assessment to investigate the feasibility of establishing a geothermal direct use for processing operations at the Refinery. The assessment included a desktop assessment and shallow drilling campaign, which confirmed little prospect in having a sufficient geothermal resource at a practical and commercially viable depth. More information on the assessment is provided in Section 4.2.1.

3.4.4 Key Assumptions and Uncertainties

Table 5 details the key uncertainties and assumptions that Worsley Alumina has identified, and which underpin the reasonable and practicable approach it is proposing for managing GHG emissions.

Table 5: Assumptions and Uncertainties in GHGMP

Assumption	Discussion
Alternative and/or innovative energy sources, infrastructure and energy efficiency technologies may become available in the future that can avoid or minimise GHG emissions	This GHGMP has been prepared based on the capacity of existing State energy infrastructure. Worsley Alumina will continue to explore feasible alternatives, including developments in State infrastructure, innovative energy sources and energy efficiency technologies (such as renewables and green hydrogen) as they develop, mature and become viable for the scale required for the Refinery which will ultimately prevent more emissions reductions opportunities/possibilities. However, at present, the nature of these alternative options and technologies, or when they may be available, is not known. More information on the consideration of renewable energy is discussed in Section 4.1.2.2.2.
Consideration of renewable energy	South32 has assumed that the market price for renewable energy technology in Western Australia will reduce over time (in alignment with increasing efficiency). The practicability of renewable energy installation for the Worsley Alumina operation is driven by the operational need for steam (see Section 3.2.2). Consideration of renewable energy will occur in alignment with the additional abatement (Section 4.2) and adaptive management approach (Section 4.1.3).
GHG emissions estimates	Scope 1 and Scope 2 GHG emissions have been estimated based from available monitoring information and published energy content and emission factors contained in *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (as amended). Scope 3 GHG emissions have been estimated in accordance with *Technical Guidance for Calculating Scope 3 Emissions (World Resources Institute, 2013*) and data sources from the *International Aluminium Institute (World Aluminium, 2015)* and *European Aluminium Association (European Aluminium Associations, 2013)*. For the purposes of emission projections over the life of the proposal it is assumed that there will be no change in emission factors.
Emissions reduction estimates	Emissions reduction estimates are based on numerical modelling calibrated against Worsley Alumina's plant performance, and where available demonstrated through existing technology already installed.
Carbon price	Consideration of carbon price is as per South32's economic assumptions. South32's view on carbon price is updated annually in response to changes in policy, technology and price benchmarks, and is reported in our annual Sustainability Development Report. South32 has a near-term view that reflects existing or imminent carbon markets, and a long-term view of a single global carbon price of US$40 per t CO2-e.
Uncertainty	**Discussion**
State, Commonwealth and International GHG Policy	GHG policy at both State and Commonwealth Government levels are continuing to evolve with a number of uncertainties, including the: • Western Australia's contribution to Commonwealth targets versus other States and Territories; • Setting of targets to 2050; and • Setting of sector specific targets for industry versus other sectors (e.g. power, transport, agriculture, buildings). Similarly, international climate policy and carbon markets continue to evolve at pace creating additional uncertainty for businesses. Worsley Alumina will continue to monitor and assess the evolution of GHG policy at both State and Commonwealth Government levels and adapt where necessary.
Biomass availability	Increasing the use of biomass for fuel presents a potential opportunity for emissions reduction at the Refinery. However, the availability of current and future biomass supply in the region is uncertain. More recently, the WA Government announced new protections for native forests in the South-West, alongside a commitment to expand WA's softwood timber plantations. The impact of these announcements on biomass supply are unclear at this early stage (see Section 4.1.2.2.2).

4 GHG MANAGEMENT PROVISIONS

This section describes the reasonable and practicable management provisions that will support Worsley Alumina to meet the objectives of the GHGMP (see Section 2.3.1).

4.1 MANAGEMENT ACTIONS

The management actions described in Sections 4.1.1 to 4.1.5 are proposed to be implemented with the Revised Proposal. It should be noted that many of the management actions are an extension of existing management activities which are being undertaken as part of the current Worsley Alumina Project. For example, the high-level decarbonisation concept study completed in 2019 continues to inform existing and future emission reduction studies and projects. Similarly, the findings of the previous geothermal and concentrated solar thermal studies (see Section 4.2) have informed the current study focus.

A key new management action under this GHGMP is the proposal for interim emissions reduction targets specific to Worsley Alumina and the Revised Proposal (see Section 4.1.1). Such targets do not currently exist under the Worsley Alumina Project's existing authorisations. South32 have set and met voluntary short-term emission reduction targets (i.e. keep FY21 Scope 1 emissions below FY15 baseline) but these have been group-wide and not specific to individual facilities or sites.

As described in Sections 4.1.3 and 4.3, Worsley Alumina will regularly monitor, evaluate and adapt the proposed management actions to improve and optimise their delivery, and report against these on an annual and five yearly basis.

Appendix B is a summary table of the management actions described in Sections 4.1.1 to 4.1.5.

4.1.1 MA1 – Establish Interim Emission Reduction Targets

As a part of this GHGMP, Worsley Alumina has proposed specific interim emissions reduction targets for its net operational emissions (Scope 1 and Scope 2), inclusive of both the BBM and Refinery. The proposed interim targets are based on five yearly increments, using the existing MS719 authorised emissions limit as a baseline and aligned with the 15-year indicative life of the Revised Proposal. The pipeline of emission reduction studies and projects described in Section 4.1.2 are designed to support Worsley Alumina to meet these targets with an aspiration, where reasonable and practical, to deliver reductions beyond the interim reduction targets.

Table 6 lists the proposed interim emissions reduction targets in absolute and percentage reduction terms for the Revised Proposal against the proposed baseline, as well as a minimum cumulative emissions reduction that would be achieved by meeting the proposed interim targets. The minimum cumulative emission reduction of 12.75 Mt CO_2-e also represents the minimum emission reductions that the Revised Proposal would contribute to lowering Western Australia's emissions towards the State's net zero goal, compared to maintaining Worsley Alumina's net emissions at its existing MS719 emissions limit.

Table 6: Interim Emissions Reduction Targets – based on MS719 Baseline (3.75mt CO_2-e)

Milestone	Interim Reduction Target (Mt CO_2-e)	% Reduction from Baseline	Min Cumulative Reduction (Mt CO_2-e) [5]
5-year target (By FY26 [6])	3.45	8%	-
10-year target (By FY31)	3.0	20%	1.5
15-year target (By FY36)	2.25	40%	5.25
Realisation of 15 year reductions			12.75

Figure 3 depicts the proposed interim reduction targets of the Revised Proposal in absolute and % reduction terms, using the existing MS719 authorised emissions limit as a baseline.

[5] The minimum cumulative reduction is calculated using the minimum year on year GHG savings that could be achieved across each five-year target period versus Worsley Alumina continuing to operate at FY21 levels. FYXX years are based on draft Revised Proposal submission and are subject to change in line with the Worsley Environmental Approval

[6] A reference to 'By FYXX' means by the end of that financial year.

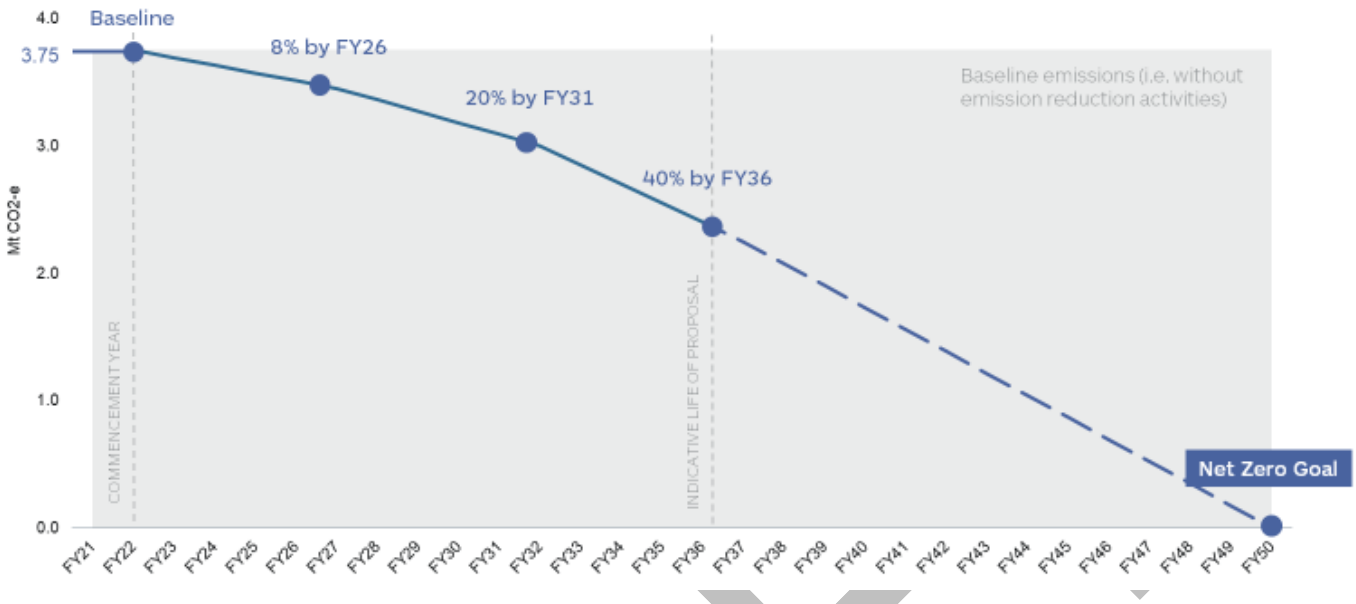


Figure 3: **Interim emission reduction targets[7] of the Revised Proposal and net zero goal**

The proposed interim targets depicted in Figure 3 are not intended to deliver a linear trajectory to net zero by 2050, but rather they have been developed to reflect all reasonable and practicable measures to decarbonising Worsley Alumina with the ultimate goal of reaching net zero by 2050. Worsley Alumina will look to accelerate emission reductions towards net zero as new technologies and solutions emerge, including lower carbon energy and developments in Western Australian energy markets, become available (see Section 4.1.2.3). The proposed interim targets for the Revised Proposal are aligned with South32's group-wide emission reduction targets and goals, but they do not replicate them, noting South32's group-wide decarbonisation strategy and medium-term emissions reduction target (i.e. to halve our operational emissions by 2035) have been developed at a whole-of-portfolio level. The interim reduction targets for Worsley Alumina reflect what is reasonable and practicable at Worsley given the nature of the operations and project, including the existing State infrastructure and availability of renewable technologies and energy.

Interim emission reduction targets beyond the proposed interim targets will be developed alongside planning for Worsley Alumina's operations beyond the life of the Revised Proposal. This will also ensure subsequent interim reduction targets are based on the best available technology and results from further studies and investigations, are reasonable and practicable, and aligned with South32's and Western Australia's medium and long-term emission reduction targets and goals.

4.1.2 MA2 – Mitigation Measures

This section summarises the key emission reduction studies and projects that Worsley Alumina are pursuing that are intended to achieve the interim reduction targets proposed for the Revised Proposal by identifying and implementing reasonable and practicable decarbonisation initiatives. These emission reduction studies and projects build on previous studies undertaken at Worsley Alumina (see Section 3.4.3) including the initial high-level decarbonisation conceptual study completed in 2019 which identified over 80 potential decarbonisation projects comprising short-term and technologically mature initiatives (e.g. process efficiency, coal to gas conversion) through to long-term, research and development initiatives (e.g. integration of renewables, process electrification).

The current emission reduction studies and projects for the Worsley Alumina Project and the Revised Proposal are focused on three primary themes:

- process efficiency activities to reduce energy consumption (Section 4.1.2.1);
- energy or fuel switching to shift our energy supply to lower carbon alternatives (Section 4.1.2.2); and;
- over the longer-term, renewable energy, technology and partnerships (Section 4.1.2.3).

[7] FYXX years are based on draft Revised Proposal submission and are subject to change in line with the Worsley Environmental Approval

In the event that it is unreasonable or impracticable for Worsley Alumina to meet the proposed interim targets through the identified studies and projects, in accordance with the mitigation hierarchy, Worsley may, if it is practicable, seek to acquire and retire carbon offsets to address the remaining shortfall (see Section 4.1.2.4) following consultation with the Department of Water and Environmental Regulation (DWER).

Figure 4 shows an indicative breakdown of emission reduction activities that will support Worsley Alumina to apply all reasonable and practicable measures to achieve the interim emission reduction targets of the Revised Proposal. It is important to note the contribution of the emission activities to the reduction pathway depicted is indicative only and based on current information. It is expected that the abatement potential of some projects which are being pursued will change as they move through their respective study phases to confirm whether they are reasonable and practicable. Given the varying stages of assessment and maturity of the emission reduction initiatives presented in this GHGMP, it is expected that the relative contribution of different initiatives to meet or exceed the interim targets will shift over time and the realised trajectory to net zero by 2050 may differ. As detailed in Section 4.1.2.4, based on Worsley Alumina's operations and current technology development trajectories, it is anticipated that residual emissions will remain in the longer-term, requiring the use of carbon offsets to achieve South32's net zero GHG emissions by 2050 goal.

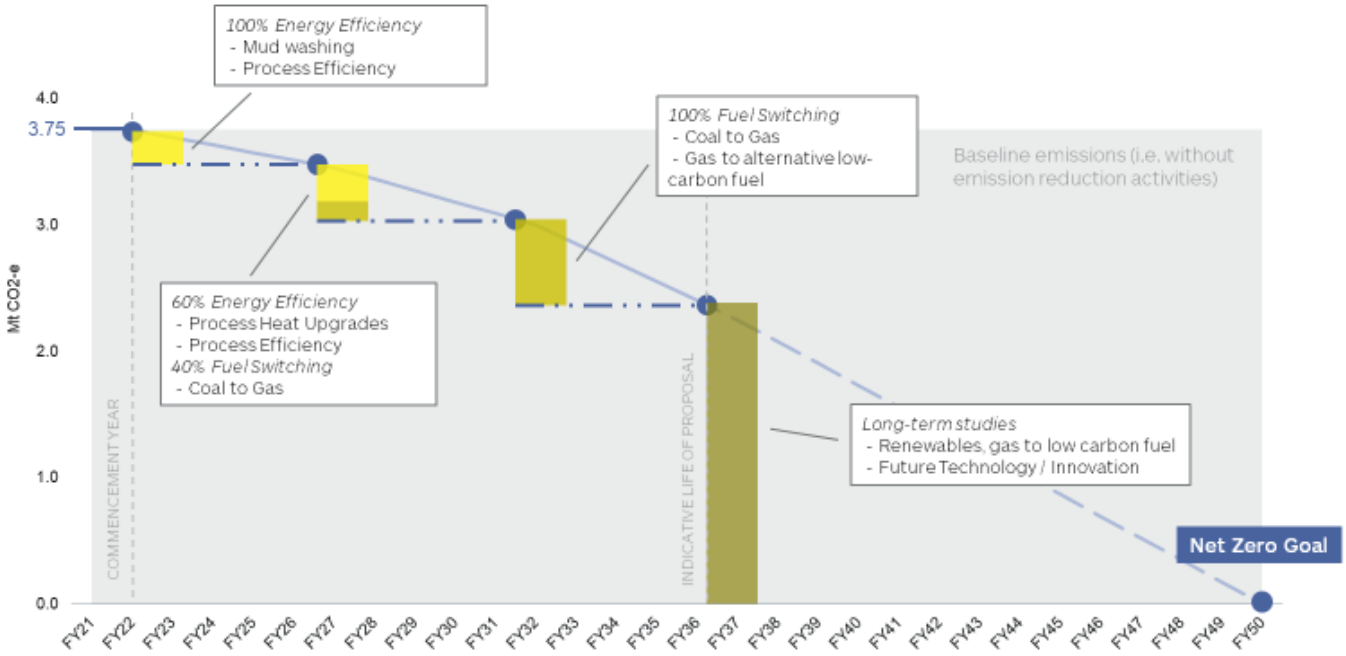


Figure 4: Interim emission reduction targets[8] and indicative breakdown of proposed emission reduction activities to achieve the targets and net zero goal.

Worsley Alumina will continue to evaluate new and existing initiatives over the life of the Revised Proposal and beyond, against a number of criteria, including safety, technical performance, operability, emissions reduction, maturity, scale, economic return and time required to adapt to changes in process or energy efficiency technologies (including technology commercialisation). Worsley Alumina proposes to provide an update on the status and maturity of these studies (and others, as appropriate) annually through the Worsley Alumina Annual Environmental Report, and also as part of the five-yearly review of the management plan outlined in Table 8.

4.1.2.1 Energy Efficiency Projects

In the short-term Worsley Alumina is pursuing energy efficiency projects which are likely to represent the most material opportunities to contribute to achieving the first interim emissions reduction target, whilst also supporting delivery of the second interim target.

The energy efficiency projects are designed to identify practicable opportunities to reduce energy consumption, operating costs, and carbon emissions by reducing the operational need for steam or more effectively using industrial heat. Mud washing is the

[8] FYXX years are based on draft Revised Proposal submission and are subject to change in line with the Worsley Environmental Approval

most mature of these (Section 4.1.2.1.1), however, additional projects are progressing through study phases such as waste heat to digestion (Section 4.1.2.1.12), Facility 50 dilution reduction, calciner flue gas heat recovery, and replacing steam ejectors with vacuum pumps. The projects are in various phases of study to determine which initiatives are reasonable and practicable, with the most mature and material of these summarised below.

4.1.2.1.1 Mud Washing

Mud separation, washing and residue pumping is a key part of the refining (Bayer) process at the Refinery. Currently under investigation is the addition of new high efficiency washers to reduce the amount of water required to wash the mud, which will in turn reduce the amount of evaporation needed, reducing the amount of energy and coal consumed to meet the reduced steam requirements. This technology has already been trialled at Worsley Alumina on mud washing Train 3. The project aims to decommission the old flat bottom washers used on trains 1 and 2 and replace with deep cone thickening technology.

Initial study estimates indicate a potential reduction in the order of 280,000 t of CO_2-e per year. The emissions reduction estimations were calculated using a Refinery Syscad Process Model, calibrated against Worsley Alumina's plant performance, in addition to demonstrated reductions from newer technology already installed in the mud washing circuit. Furthermore, key assumptions made in the design have been verified by trialling on the existing Train 3.

A number of practical design ideas are being investigated through to the end of pre-feasibility for final selection prior to an investment decision to proceed into the next study phase (feasibility). As the project progresses through the remaining study phases and to execution, emission reductions could start to be realised by FY25.

4.1.2.1.2 Waste Heat to Digestion

The digestion facility of the Refinery uses steam generated directly from Worsley Alumina's coal fired boilers to heat up incoming process streams. At another area of the Refinery, excess energy is rejected into the cooling lake as waste heat. The objective of the Waste Heat to Digestion study is to investigate modifications and upgrades to the Refinery that will allow the re-use of the waste heat to pre-heat incoming process streams into the digestion circuit. This reuse of the waste heat will reduce the amount of direct steam required in the digestion facility and consequently reduce the Refinery's coal consumption and GHG emissions.

The project is currently transitioning to prefeasibility study phase after identifying a suite of potential concepts that could meet the project objective. The concepts vary in terms of cost/benefits, savings, technical complexity and operational risks, with early emission reduction estimates varying between 60,000-250,000 tonnes of CO_2-e per year.

Further engineering investigations are required as part of the prefeasibility study to confirm if the initiative is reasonable and practicable, and if it will progress through the prefeasibility tollgate to feasibility.

4.1.2.2 Fuel Switching

Switching our primary source of energy to lower carbon alternatives is a key strategy for reducing emissions from the Revised Proposal. This transition is also important to support the development of lower carbon energy markets in Western Australia and to improve our long-term energy security.

Worsley Alumina are completing studies to detail the optimal approach to reduce the use of coal, with a pre-feasibility study for conversion of the existing coal-fired boilers to natural gas on-track for completion in FY22 (See Section 4.1.2.2.1). As previously stated, the Refinery has been in operation for over 35 years with the design in advance of 40 years of age. The Concept Level Decarbonisation studies undertaken in 2019 acknowledged that there will be significant challenges in the adaptation and retrofitting required for the conversion from coal to an alternative fuel source.

South32 considers that the conversion to natural gas will likely serve as a transitional fuel solution. Worsley Alumina proposes to continue to investigate and progress studies to achieve the final state energy supply requirements. This will include consideration of sourcing power from green hydrogen, electrification, and other adequate renewable power supplies. These are not currently available at the necessary scale or maturity to produce process steam for the Refinery. These options will require investment in energy infrastructure at the Refinery, as well as SWIS grid infrastructure (such as pipelines) and will require a coordinated approach with other stakeholders.

4.1.2.2.1 Coal to Gas Conversion

The coal to gas conversion study is evaluating the technical and commercial feasibility of displacing coal as the primary fuel source to the coal and multi-fuel cogeneration boilers on site. Fuel switching initiatives such as coal to gas conversion are primarily a medium-term decarbonisation initiative and are proposed to be the major contributor in achieving the second interim emissions reduction target. The study estimates that gas as a replacement for coal could deliver a potential emission reduction in the order of 15-20% of the Refinery's total annual emissions, after the delivery of the energy efficiency projects.

A pre-feasibility study was recently completed on options to convert our conventional pulverised fuel boilers from coal to natural gas fired, assessing if gas can be used as a co-firing option and/or complete conversion of the facility to utilise gas. A coal & gas co-firing (allowing up to 100% gas firing) has been recommended to progress to feasibility study.

A concept study of the multi-fuel cogeneration facility has also been completed investigating the full conversion to gas and removing the capability for solid fuel firing (i.e. coal and biomass). This facility consists of two fired natural circulation reheat circulating fluidised bed boilers which are currently fired by coal (main), biomass (alternative supplementary) or diesel (start-up).

It is important to note that our transition away from thermal coal may impact the Collie community and surrounding region, which has a long history of coal mining. Our management approach takes account of these impacts to ensure they are well managed and aim to create new opportunities for people and businesses impacted by the transition. Section 4.1.4 details our approach to Just Transition.

4.1.2.2.2 Biomass

In 2018, Worsley Alumina commenced a trial to utilise timber waste product (biomass) as a fuel source in the multi-fuel cogeneration boilers to reduce coal use and carbon emissions. Biomass is sourced via the Forest Products Commission and includes waste residues from saw log operations, mine site thinning's or energy crop material. Worsley Alumina has successfully utilised between 10,000 and 16,000 bone dry metric tonnes per year since the commencement of the trial, and while the emissions abatement per tonne of biomass consumed varies between loads (due to level of moisture and/or varying calorific value of the timber waste product) we estimate that we have reduced our carbon emissions by more than 65,000 t CO_2-e since the commencement of the project.

In FY20, Worsley Alumina progressed a pre-feasibility study to increase biomass to up to 30% of the multi-fuel cogeneration facility's capacity, which is in the order of 200,000 bone dry metric tonnes per year. While the study found increased biomass usage at these rates is technically feasible and may support regional economic diversification, it also identified supply chain and safety challenges associated with sourcing and processing higher volumes of biomass. Accordingly, biomass is expected to remain a short-term complementary activity as Worsley Alumina deliver its more material efficiency and energy transition projects. More recently, the WA Government announced new protections for native forests in the South-West, alongside a commitment to expand WA's softwood timber plantations. The impact of these announcements on biomass supply are unclear at this early stage.

It should be noted that the use of biomass will cease if the multi-fuel cogeneration boilers are converted to gas firing (see Section 4.1.2.2.1).

4.1.2.3 Long-term Studies and Future Technology

As discussed in previous sections, existing energy markets and infrastructure in Western Australia do not currently support the commercial deployment of renewable energy alternatives such as hydrogen or electrification. Hydrogen markets will need to develop substantially to become a viable alternative for Worsley Alumina (given the scale of energy requirements for the Refinery). In addition, the SWIS network in its current form does not support the volume of electricity required for the Refinery should we fully electrify our processing technology using renewable energy from the grid. Based on preliminary calculations, it is expected that an increase in the order of 40% of the peak demand in the SWIS is required to enable full electrification at Worsley Alumina, without factoring in other sites and industries which may also be seeking to increase their use of renewable energy from the SWIS should it be successfully decarbonised.

Regardless, we expect future technology and renewables to play a role in our emission reduction pathway in the medium to long term (potentially beyond the life of the Revised Proposal) as technology evolves, and commercialisation of renewable energy sources mature. Accordingly, we are studying opportunities to support the transition and are working with government and industry to develop new and innovative technology solutions and low-carbon energy markets in Western Australia. Our ambition is to play a leading role in this transition, including the potential emergence of the hydrogen sector.

4.1.2.3.1 Renewables

Worsley Alumina will continue to monitor renewable technologies that offer potential abatement opportunities for longer term reduction solutions. For example, future electrification of Worsley Alumina processing technology could feasibly be powered by renewable energy, reducing net emissions. The shift from thermal coal to natural gas is designed as an interim step until low-carbon energy options at scale are commercially viable.

As previously noted, the practicability of renewable energy installation for the Worsley Alumina operation is driven by the operational need for steam (not for electricity) in the Bayer alumina refining process. This means that large-scale deployment of renewable energy such as solar PV and wind, which do not generate steam directly, would require a fundamental change to the energy infrastructure of the refinery and connection with the grid to realise the abatement potential. This would require significant and economically unfeasible investment to replace the existing process infrastructure.

South32 are engaging with government, industry and other partners, to support the development of low-carbon energy markets and policy that could underpin the decarbonisation of the south-west energy grid and the emergence of a hydrogen economy.

4.1.2.3.2 Industry Partnerships

In addition to Worsley Alumina's own emission reduction studies and project activities, we leverage and accelerate our efforts by collaborating with other companies, industry groups and research organisations to investigate low-cost and innovative solutions. These are summarised in Table 7 and are being pursued to identify practical and reasonable future emission reduction solutions that can be applied to the Revised Proposal and further reduce emissions in the longer term.

Table 7: Summary of current partnerships and industry forums relevant to long-term studies

Membership / Partnership	Description
International Council on Mining and Metals	South32 is a member of the International Council on Mining and Metals (ICMM), an international organisation dedicated to a safe, fair and sustainable mining and metals industry. The ICMM works to strengthen environmental and social performance and serve as a catalyst for change, enhancing the mining industry's contribution to society. One initiative that the ICMM are working on is the 'Innovation for Cleaner, Safer Vehicles' (ICSV) initiative. The ICSV initiative aims to reduce GHG emissions by promoting operational and technological innovation, achieved by introducing greenhouse gas emission-free surface mining vehicles by 2040, and minimising the operational impact of diesel exhaust by 2025.
Heavy Industry Low-carbon Transition Collaborative Research Centre	South32 is a founding member of the Heavy Industry Low-carbon Transition (HILT) CRC, which is a collaborative venture between industry, government and research organisations, formed to develop and accelerate technologies for heavy industry to transition to net zero. It is based on creating a framework to collaborate and share knowledge with industry partners and lower the cost of trialling new technology. The evaluation of potential low-carbon solutions for alumina production is a key interest for Worsley Alumina, given the limited maturity of alternative low-carbon processing and technology options. HILT CRC programs of specific interest to Worsley Alumina include investigations into technologies and processes for high-temperature calcination and low temperature heat in the Bayer refining process. The Australian Government has provided A$39 million of funding under its CRC Grants program. This is backed by an additional A$176 million of funding and in-kind support from industry, government and research institutions.
Electric Mine Consortium	In FY21, South32 became a founding member of the Electric Mine Consortium (EMC). The EMC aims to accelerate progress toward a fully electrified zero carbon and zero particulates mining operation. Five of the EMC's six core workstreams align to Worsley Alumina's needs including: • Mine design; • Light battery electric vehicles and ancillary equipment; • Surface and long road haulage; • Energy storage; and • Electrical infrastructure. Participation in the EMC will enable Worsley Alumina to make informed decisions about technology options through an improved understanding of readiness, while also accelerating the intake of knowledge through direct and indirect trials.

4.1.2.4 Carbon Offsets

In accordance with the objectives of this GHGMP and GHG Emissions Environmental Factor Guideline (EPA, 2020b), Worsley Alumina will seek to avoid and mitigate emissions from the Revised Proposal as a first priority. In the event that it is

unreasonable or impracticable for Worsley Alumina to meet the proposed interim targets through the identified studies and projects, in accordance with the mitigation hierarchy, Worsley Alumina may, if it is practicable, seek to acquire and retire carbon offsets to address the remaining shortfall following consultation with DWER.

Based on Worsley Alumina's expectations of the life of project operations and current technology development trajectories, it is anticipated that some carbon credits may be required to offset the residual and 'hard to abate' emissions in the long term, particularly where decarbonisation alternatives remain undeveloped, or not technically or economically feasible.

South32's approach to acquiring carbon offsets include procurement, partnership and self-generation strategies established under reputable carbon crediting schemes. Partnership and self-generation projects may include land (e.g. reforestation, savanna burning) or industry (e.g. fuel switching and efficiency) methods, and often provide additional co-benefits for the environment or local communities. It should be noted that some preliminary discussions with carbon project developers and assessments of land abatement potential surrounding Worsley Alumina have been conducted to identify potential opportunities in relation to offset opportunities.

Worsley will explore the use of Australian Carbon Credit Units (ACCU's) generated under the Australian Governments Emissions Reduction Fund should offsets be required, with a preference for ACCU's generated from local projects and those that create additional co-benefits. However, it is feasible that alternative offsets may also be used in the longer term should an international offset market develop that enables international transfers between reputable schemes.

In accordance with the GHG Emissions Environmental Factor Guideline (EPA, 2020b), offsets utilised under the Safeguard Mechanism would also be recognised as a contribution to the interim emission reduction targets proposed in this GHGMP.

4.1.3 MA3 – Adaptive Management, Monitoring and Review

Worsley Alumina will apply this GHGMP in accordance with an adaptive management approach that enables Worsley Alumina to adapt and respond to changing circumstances, optimise the delivery of the proposed and future management actions, with an aspiration, where reasonable and practical, to out-perform and not just meet the interim reduction targets. In line with this, Worsley Alumina will regularly monitor, evaluate, review and update its approach to take account of:

- Changes to the key uncertainties or assumptions, as outlined in Section 3.3.4;
- New and relevant data/information gained as a result of implementing this GHGMP;
- Maturation of emerging low-carbon technologies, innovations and energy markets that may be applicable to the Revised Proposal;
- Effectiveness of existing GHG emission reduction measures;
- Changes to internal processes, policies and procedures to manage GHG emissions; and
- Changes in State or Commonwealth legislation or policy.

Worsley Alumina has a robust monitoring and reporting program (refer to Table 8) in place to quantify GHG emissions for compliance purposes. This information will also be used monitor performance against the interim emissions reduction targets, review the effectiveness of GHG emission measures and adjust the approach to seek to achieve the objectives of this plan.

Outcomes of any reviews or updates to the management approach will be reported in the Worsley Alumina Annual Environment Report (see Section 4.3) and as part of the five yearly review and revision of this GHGMP (see Section 4.1.3.1).

4.1.3.1 Review and Revision of GHGMP

Worsley Alumina will review and revise this GHGMP at least every five years to ensure the management actions outlined within the plan continue to support delivery of the interim emission reduction targets, with consideration given to completed studies and material advancements in emerging technology and energy markets. The revised GHGMP will be provided to DWER for approval. During a review of the GHGMP, Worsley Alumina will prepare a summary plan and progress statement, to be made publicly available The document will outline key information from the GHGMP (and reports to that time), and compare the operations against other proposals, and against relative contributions to the achievement of EPA objectives for the State. The summary will include:

- a graphical comparison of emission reduction commitments in the GHGMP with 'actual' emissions for compliance periods;
- proposal performance against benchmarking for comparable facilities emissions intensity;
- a summary of emission reduction measures undertaken by the proponent; and

- a clear statement as to whether interim targets have been achieved.

Any subsequent revisions of the GHGMP will remain aligned with South32's group-wide targets and goals, EPA objectives and State and/or Commonwealth legislation and policy.

4.1.4 MA4 – Just Transition Planning

As one of two major industrial users of energy coal in Collie, our plan to transition away from this energy source will impact people and businesses that support the industry. Accordingly, we are committed to working with government, the community and other stakeholders to support a fair and equitable transition for Collie.

We are a member of the Collie Just Transition Working Group which developed the Just Transition Plan for Collie (DPC, 2020), released in December 2020. The purpose of this plan is to create a strong and sustainable future for Collie, its workforce and community as it shifts away from energy coal. The plan was developed in collaboration with a variety of stakeholders, including representatives from local industry, community, unions and government. In June 2021, Worsley Alumina signed the Just Transition Working Group Memorandum of Understanding, committing to support the implementation of the Just Transition Plan for Collie in a positive, collaborative and cooperative manner that seeks to deliver a sustainable and positive future for Collie, its workforce and community.

The management actions contained in this GHGMP will take account of just transition impacts and seek to realise new opportunities including new jobs, technologies, emerging industries and increased investment, for the community.

Worsley Alumina will undertake a Just Transition Risk Assessment to better understand the potential risks and opportunities to benefit people and communities through the energy transition. It is expected that the outcomes of this work will inform South32's ongoing participation in the implementation of the *Just Transition Plan for Collie*.

4.1.5 MA5 – Addressing Value Chain Emissions

Aluminium smelting involves the electrolytic reduction of alumina to produce liquid aluminium, with the electricity required for this process being a large source of carbon emissions. Achieving net zero operational carbon emissions in the aluminium value chain requires the development of low carbon electricity at scale, along with commercialisation of alternative processing and energy efficiency technologies, such as inert anodes and application of AP3XLE technology. South32 is trialling the latter of these technologies at the Hillside Aluminium smelter, which if successful, will enable reductions of an estimated 150,000 to 200,000t CO2-e per annum once the pot relining program is complete.

The most material emission reduction opportunity in South32's aluminium value chain relates to securing low-carbon electricity for Hillside Aluminium, which sources its electricity from the thermal coal-fired South African electricity grid. At Mozal Aluminium, most electricity is supplied from hydroelectric power generated by Hidroelectric Cahora Bassa, situated on the Zambezi River in the northwest of Mozambique. Accordingly, in 2020 South32 established a project team to fast-track studies to assess affordable, low-carbon electricity options at Hillside Aluminium. Concurrently, South32 are also engaging with the South African Government, Eskom and other potential partners to identify options for renewable energy infrastructure that will support the decarbonisation of the South African grid, beyond the South African Government's decarbonisation commitment, as outlined in South Africa's Integrated Resource Plan 2019. A coordinated approach is critical to reduce carbon emissions at Hillside Aluminium while supporting the growth of the South African economy as the world transitions to a low-carbon future.

While these initiatives will not impact Worsley Alumina's Scope 3 profile due to them already being accounted for as a downstream facility in accordance with the GHG Protocol Technical Guidance for Calculating Scope 3 Emissions (World Resources Institute, 2013), they do demonstrate South32's commitment to addressing GHG emissions throughout our value chain. Worsley Alumina will report on these value chain studies and initiatives, and potential impact on Worsley Alumina's Scope 3 emissions as part of Worsley Alumina's annuals reports as described in Section 4.3.

Beyond South32's own facilities, we are committed to addressing and reducing value chain emissions through building partnerships with customers and suppliers, participating in industry groups and product stewardship initiatives, and supporting innovative technology solutions. In 2021, South32 also committed to assessing options to set a target for Scope 3 emissions to complement our operational emission reduction targets and goals. Worsley Alumina will report on these value chain studies and initiatives, and potential impact on Worsley Alumina's Scope 3 emissions as part of Worsley Alumina's Annual Environmental Report.

South32's Mozal Aluminium smelter, which sources its alumina from Worsley Alumina, has joined the Aluminium Stewardship Initiative (ASI). The ASI is a global industry-led certification organisation focused on the responsible production of aluminium from mine to customer. A key criterion for ASI certification is emissions performance, which will be supported through decarbonisation initiatives across South32's alumina and aluminium activities, including at Worsley Alumina.

4.2 ALTERNATIVE ABATEMENT OPTIONS

As referenced in Sections 3.3.3 and 4.1.2, the management measures proposed in this GHGMP build on previous studies undertaken at Worsley Alumina, such as the high-level decarbonisation conceptual study completed in 2019. While not all of these projects have been progressed into subsequent study phases, they will continue to be revisited over time to test whether previous technological or economic barriers have shifted to a degree that justifies further study.

Similarly, should Worsley Alumina's engagement with government, industry and other partners, realise new low-carbon energy markets or technologies South32 may revisit many of the concepts previously studied, but not considered reasonable or practicable at that time.

While the projects described in the sections below were not reasonable or practicable for the Worsley Alumina Project at the time they were completed, they have informed the direction of Worsley Alumina's decarbonisation studies and activities, as described in Section 3.1.2.

4.2.1 Geothermal

A preliminary assessment of geothermal potential at Worsley Alumina investigated the feasibility of establishing a geothermal direct use system within close proximity (10 km) of the Refinery. The concept was based on the premise that hot water (at the required temperature of between 120-130°C) was available in the surrounding area, thus eliminating the requirement to heat water at the Refinery for use in processing operations, as per normal operational practice.

A desktop assessment was undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Horowitz et. Al, 2008) and involved the collation of available geothermal data for both the sedimentary and cratonic rocks of the region. This led to a targeted exploration program being developed, including both seismic and shallow drilling in the first phase (i.e. first two years), with deep drilling, proof of temperature, heat capacity and liquid flow assessments in the second phase (i.e. years three to six). The seismic and shallow drilling studies confirmed a lack of prospect in having a sufficient geothermal resource at a practical and commercially viable depth. Based on the outcomes of the desktop assessment, coupled with the results of the shallow drilling, the decision was made not to proceed with the second phase of the exploration program.

The geothermal initiative is currently not being progressed by Worsley Alumina due to the uncertainty and risk surrounding available geothermal resource and the required technical solution. It has been identified for further monitoring, particularly if future developments are made in high temperature heat pump technology.

4.2.2 Concentrated Solar Thermal

Worsley Alumina engaged CSIRO to gain a greater understanding of the options for incorporating a Concentrated Solar Thermal (CST) system to assist with energy production and heat generation and assess the site for its suitability and feasibility. CST technology is broadly defined as any technology that utilises mirrors or lenses to capture solar radiation in order to heat an object smaller than the area of incident natural solar radiation.

The Worsley Alumina site receives an annual energy exposure of over 2,000 kWh/year, which is considered to be fair in comparison to the global scale. However, the site does incur a high season variability (summer periods receiving 2 ½ times more energy than the winter periods) and can be exposed to periods of inclement weather.

Amongst other matters, a key hurdle for all of the options provided by CSIRO, was that the installation of a CST system would require a very large footprint of 500-800 ha, in order to provide any significant reduction in energy consumption, the size of which makes this technology unviable for the operation.

4.3 REPORTING AND PUBLIC DISCLOSURE

Worsley Alumina undertakes regular reporting of performance against our targets and management approach in accordance with a number of regulatory (e.g. NGER Act) and voluntary schemes (e.g. TCFD). A list of key reporting requirements associated with the GHGMP and Revised Proposal are summarised in Table 8.

In addition to the reporting process summarised in Table 8, South32 also produces an annual Sustainable Development Report. The reports are prepared in accordance with the recommendations of the Task Force on Climate-related Financial Disclosures and are released in September each year. These reports are publicly available on the South32 website (www.south32.net).

To verify the accuracy of reported emissions, internal and external environmental audits are undertaken. Worsley Alumina gains external assurance for the contents of NGER Act reporting submissions on an annual basis, by an auditor accredited under the NGER Act.

Table 8: GHG Reporting Requirements

Aspect	Description	When	Recipient
Worsley Alumina Annual Environmental Report	Performance against commitments outlined in this GHGMP, as part of broader annual reporting against relevant environmental approvals conditions. This will include a summary of emissions performance for the corresponding financial year, and an update on progress against the interim emission reduction targets including any material advancements in the project and study portfolio outlined in Section 4.1.	Annually by 30th Sept	Department of Water and Environmental Regulation (DWER)
GHGMP	Worsley Alumina will publish this GHGMP once finalised, and each subsequent revision as detailed in Section 4.1.3.1. The five yearly review and revision of the GHGMP is intended to ensure the management actions outlined within the GHGMP continue to: • support delivery of emission reductions against the interim targets, and • consider material advancements in emerging technology and configuration of the SWIS network, and • align with South32's group-wide targets and goals, EPA objectives and State and/or Commonwealth legislation and policy. During a review of the GHGMP, Worsley Alumina will prepare and make publicly available a summary plan and progress statement as outlined in Section 4.1.3.1 The revisions will coincide with the commencement of the next interim emissions reduction target period and include a summary of progress of the preceding five years in an accessible form to be made available on the South32 website (www.south32.net).	By the 30th Sept 2027 and every fifth 30th Sept thereafter, unless triggered earlier	DWER
Emissions and Energy Reporting (Commonwealth)	Annual reporting of Scope 1 and Scope 2 GHG emissions, energy production and energy consumption in line with *National Greenhouse and Energy Reporting Act 2007,* and associated measurement determination. The annual reporting under NGERs is also currently used to report performance against Safeguard Mechanism baseline established under the *National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015.* Worsley Alumina's current transitional calculated baseline is 3,718,777 tonnes CO_2-e (applies until 30 June 2022). It applies to Scope 1 emissions at both the BBM and Refinery, which are treated as a single facility under the scheme. The data is published by the Clean Energy Regulator (CER) as part of annual Safeguard Mechanism data tables. This occurs by 28th February the following calendar year (www.cleanenergyregulator.gov.au).	Annually by 31st Oct	CER

5 STAKEHOLDER CONSULTATION

Worsley Alumina maintains ongoing consultation with key government agencies through the Environmental Management Liaison Group (EMLG). The EMLG consists of representatives from various State Government departments including the Department of Jobs, Tourism, Science and Innovation, the Department of Biodiversity, Conservation and Attractions, the Department of Water and Environmental Regulation, the Department of Primary Industries and Regional Development and the Department of Mines, Industry Regulation and Safety. Other interested parties (such as the Department of Agriculture, Water and the Environment) may be involved in the EMLG on an invitational basis. Worsley Alumina will continue to maintain consultation with these key government agencies throughout the implementation of the Revised Proposal

Stakeholder engagement occurs through the Community Liaison Committees, which include representatives from local Shires, communities and conservation groups. Worsley Alumina will continue to utilise the CLC's throughout the life of the Revised Proposal.

A summary of stakeholder consultation undertaken in support of the Revised Proposal is provided in Appendix C of the Worsley Mine Expansion Environmental Review Document (South32, 2021). Any changes in relation to consultation processes (associated with GHG management) will be captured in subsequent revisions of this GHGMP.

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7 DEFINITIONS, TERMS AND ABBREVIATIONS

Term	Description
ACCUs	Australian Carbon Credit Units
BBM	Boddington Bauxite Mine
CER	Clean Energy Regulator
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CST	Concentrated solar thermal
EMC	Electric Mine Consortium
EMLG	Environmental Management Liaison Group
EPA	Environmental Protection Authority
EP Act	*Environmental Protection Act 1986* (WA)
FY	Financial Year (End of)
GHG	Greenhouse Gas
GHGMP	Greenhouse Gas Management Plan
HFC	Hydrofluorocarbons
HILT	Heavy Industry Low-carbon Transition
ICMM	International Council on Mining and Metals
ICSV	Innovation for Cleaner, Safer Vehicles
kt	Kilotonne
LoOP	Life of Operations Plan

Term	Description
MA	Management action
MFC	Multi Fuel Cogeneration Power Plant
ML/a	Megalitres per annum
MS719	Ministerial Statement No. 719
Mt	Million tonnes
Mtpa	Million tonnes per annum
MW	Megawatt
NGER	National Greenhouse and Energy Reporting
NGER Act	*National Greenhouse and Energy Reporting Act 2007* (Cth)
RLA	Refinery Lease Area
SF_6	Sulfur hexafluoride
SWIS	South West Interconnected System
TCFD	Taskforce for Climate Change Financial Disclosure
tpa	tonnes per annum
Worsley Alumina	South32 Worsley Alumina Pty Ltd

8 DOCUMENT CONTROL

Reviewer Circulation

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APPENDICES

Appendix A Worsley Bauxite-Alumina Operation Greenhouse Gas Benchmarking Study (Ramboll, 2020)

Intended for
KASA Consulting c/o South32 Worsley Alumina Pty Ltd

Document type
Report

Date
November 2020

GREENHOUSE GAS BENCHMARKING STUDY FOR THE WORSLEY ALUMINA MINE EXPANSION REVISED PROPOSAL (EPA ASSESSMENT NO. 2216)

RAMBOLL Bright ideas. Sustainable change.

GREENHOUSE GAS BENCHMARKING STUDY FOR THE WORSLEY ALUMINA MINE EXPANSION REVISED PROPOSAL (EPA ASSESSMENT NO. 2216)

Project name	**Greenhouse Gas Benchmarking Study for the Worsley Alumina Mine Expansion Revised Proposal (EPA assessment no. 2261)**
Project No.	**3180010058**
Recipient	**KASA Consulting c/o South32 Worsley Alumina Pty Ltd**
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ACRONYMS AND ABBREVIATIONS

%	Per cent
°C	Degrees Celsius
BBM	Boddington Bauxite Mine
CBG	Compagnie des Bauxites de Guinée
CER	Clean Energy Regulator
CH_4	Methane
cm	Centimetres
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DAWE	Commonwealth Department of Agriculture, Water and the Environment
DISER	Commonwealth Department of Industry, Science, Energy and Resources
EIA	Environmental Impact Assessment
EP Act	*Environmental Protection Act 1986*
EPA	Environmental Protection Agency
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EPL	Environmental Protection License
FY	Financial year
GHG	Greenhouse Gas
ha	Hectares
HFC	Hydrofluorocarbons
IAI	International Aluminium Institute
kg	Kilogram
km	Kilometres
MJ	Megajoule
Mtpa	Million tonnes per annum
N_2O	Nitrous oxide
NGER	National Greenhouse and Energy Reporting
NGER Act	*National Greenhouse and Energy Reporting Act 2007*
NSW	New South Wales
QAL	Queensland Alumina Ltd
QLD	Queensland
SF_6	Sulphur hexafluoride
South32	South32 Worsley Alumina Pty Ltd

SWIS	Southwest Interconnected System
t	Tonnes
The mine	The Boddington Bauxite Mine owned by South32 Worsley Alumina Pty Ltd
The proposal	The Worsley Mine Expansion
The refinery	The Worsley Alumina Refinery owned by South32 Worsley Alumina Pty Ltd
TJ	Terajoule
tpa	Tonnes per annum
WA	Western Australia

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1. INTRODUCTION

1.1 Background

South32 Worsley Alumina Pty Ltd (South32) currently operates the Boddington Bauxite Mine (BBM) (the 'mine'), located approximately 5 kilometres (km) west-south-west of Boddington and the Worsley Alumina Refinery (the 'refinery') located approximately 15 km north-west of Collie. Collectively, the mine and the refinery are referred to in this document as the 'Worsley Bauxite-Alumina operation'.

The current mining and refinery operations are regulated via conditions in Part A of Ministerial Statement No. 719 (Part IV of the *Environmental Protection Act 1986* (EP Act)), licenced through Environmental Protection Licences (EPLs) as issued under Part V of the EP Act L5960/1983/11 (mine) and L4504/1981/17 (refinery), and exemptions through the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The existing bauxite mining activities are undertaken in what is referred to as the "Primary Bauxite Area", which is comprised of the Saddleback, Marradong, and Hotham North areas. The mine is licensed for a production rate of 18.8 million tonnes per annum (Mtpa).

The existing bauxite mining areas and refinery are connected by a 50 km overland conveyor. Ore is processed at the refinery, using the four-stage Bayer Process to transform the red bauxite rock into white alumina powder. The Bayer process extracts alumina from bauxite through crushing, dissolving it in caustic soda, filtration and an electrolytic process. The alumina is then transported 55 km by rail to the Port of Bunbury for export. The refinery is licensed for a production capacity of 4.7 Mtpa.

South32 is seeking approval for the 'Worsley Mine Expansion' (the 'proposal'). The proposal includes:

- continuation of existing operations at the BBM, overland bauxite conveyor (OBC) and Refinery
- expand the existing mining envelope at the BBM to be encompassed by the Worsley Mining Development Envelope
- development of a Bauxite Transport Corridor at the BBM, with optionality for roads and/or conveyor
- development of a Contingency Bauxite Mining Area and maintenance work at the refinery
- development of associated mine/support infrastructure
- ongoing continuation of minor infrastructure activities and regional exploration programs.

The proposal involves clearing of up to 5,841 hectares (ha) of native vegetation for the mine and mining related activities. The proposal also requires two river crossings over the Hotham River, as well as several culvert crossings of minor tributaries. No changes to the refinery are proposed. The production rates of the mine and refinery would remain unchanged.

During consultations with the Western Australian Environmental Protection Authority (EPA) and the Department of Agriculture, Water and the Environment (DAWE), it was identified that a greenhouse gas (GHG) assessment and a GHG management plan would be required as part of the proposal. In accordance with the EPA's *draft Content of a Greenhouse Gas Management Plan*, benchmarking against other comparable projects is required.

This document outlines a GHG benchmarking study for the Worsley Bauxite-Alumina operation. The scope of the benchmarking study includes the refinery and the proposed mine operations.

1.2 Document purpose

The majority of benchmarking analyses and life-cycle assessments relating to the alumina industry generally relate to alumina production and do not provide a holistic assessment that includes bauxite mining. Therefore, the purpose of this document is to provide a holistic assessment of the bauxite mining and alumina refining activities associated with the Worsley Bauxite-Alumina operation.

The purpose of this Benchmarking Study is to provide:

1. Background on the current emissions profile for the Worsley Bauxite-Alumina operation (mine and refinery operations).
2. An estimation of the GHG efficiency of the proposal (i.e. GHG emissions per unit of product and/or other agreed performance indicators).
3. A comparison with the GHG efficiencies of other comparable Worsley Bauxite-Alumina operations producing a similar product, both within Australia and overseas.
4. Contextualisation of the emission intensity benchmarks with regard to published latest guidance, including prescribed production variables and default emissions intensity values as defined under the National Greenhouse and Energy Reporting (NGER) Safeguard Mechanism Rule.

1.3 Document scope

This report quantifies the GHG emissions associated with:

- Scope 1 'direct' GHG emissions (e.g. from energy production, combustion in vehicles and other equipment etc.)
- Scope 2 'indirect' GHG emissions from electricity consumption.

Scope 3 'other indirect' GHG emissions are not considered in this Benchmarking Study based on limited publicly available data. Scope 3 emissions account for all other indirect or 'downstream' GHG emissions resulting from a company's activities but occurring from sources not owned or controlled by the company (e.g., product transport or combustion).

The GHG emissions intensity in this study is reported in carbon dioxide equivalent (CO_2e) tonnes per tonne product (i.e., t CO_2e/t product).

2. SECTOR OVERVIEW

2.1 Bauxite mining

2.1.1 Global context

Bauxite is generally found in areas around the equator in tropical and sub-tropical regions. It contains between 25 to 30 per cent (%) of alumina.

Table 2-1 lists the approximate values for bauxite production globally and the estimated reserves. In the global market, some of the largest bauxite mining countries are Australia, Guinea, China, Brazil and India, comprising a combined 84% share of total global bauxite production in 2019.

The global bauxite mine production is expected to be marginally affected by the COVID-19 pandemic and is forecast to decline by just 0.1% to 344 Mt in 2020. Despite this, production forecasts over the next four years (2021 to 2024) is expected to grow at a compound annual growth rate of 2.8%, to reach 387.4 Mt in 2024, with Australia, Guinea, India, Jamaica and Kazakhstan being the five largest suppliers (GlobalData, 2020).

Table 2-1: Global bauxite mine production and reserves (2019)

Country	Bauxite production (t)[1]	Percentage of global production	Estimated reserves (t)[1]
Australia	100,000,000	27	6,000,000,000
Guinea	82,000,000	22	7,400,000,000
China	75,000,000	20	1,000,000,000
Brazil	29,000,000	8	2,600,000,000
India	26,000,000	7	660,000,000
Indonesia	16,000,000	4	1,200,000,000
Other	15,000,000	4	5,000,000,000
Jamaica	8,900,000	2	2,000,000,000
Russia	5,400,000	1	500,000,000
Vietnam	4,500,000	1	3,700,000,000
Saudi Arabia	4,100,000	1	200,000,000
Malaysia	900,000	<1	110,000,000
United States	Data withheld	Not determined	20,000,000
Global Total	**370,000,000**	**100**	**30,000,000,000**

[1] (U.S. Geological Survey, Mineral Commodity Summaries, 2020)

2.1.2 Australian context

Australian bauxite deposits have high grades, are shallow and relatively easy to mine. Australia is the largest producer of bauxite (Table 2-1), with five large mines supplying around 30% of global production (Australian Aluminium Council, 2020).

The five major Australian bauxite mines according to the Australian Aluminium Council (2020) are:

- Weipa (Queensland) – Rio Tinto
- Huntly (Western Australia) – Alcoa
- Boddington (Western Australia) – South32
- Gove (Northern Territory) – Rio Tinto
- Willowdale (Western Australia) – Alcoa.

2.2 Alumina refining

2.2.1 Global context

Figure 2-1 shows the estimated global alumina production over the last ten years as reported by the International Aluminium Institute (IAI). The total global alumina production in 2019 was estimated to be approximately 131,900 t. Over the past ten years, China has remained the world's leading producer of alumina, producing an estimated 71,284,000 t of alumina in 2019. This equates to approximately 54% of the total estimated global production. Australia (termed 'Oceania' by the IAI) ranks as the second highest producer with an estimated 20,491 t of alumina produced in 2019, approximately 15.5% of the total estimated global production (International Aluminium Institute, 2020).

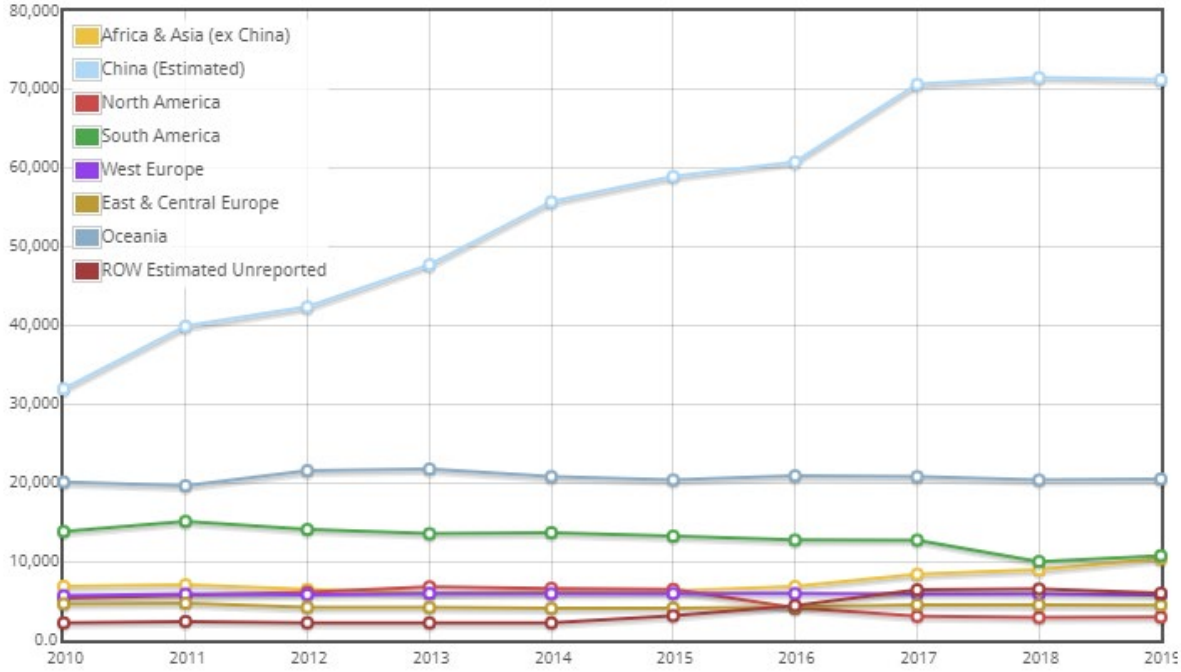

Figure 2-1: Global alumina production (tonnes) from 2010 to 2019

Source: (International Aluminium Institute, 2020)

2.2.2 Australian context

Australia alumina production in 2018 was 20.3 Mt. Australia maintained its position as the second largest producer of alumina and the world's largest exporter, with 17 Mt exported in 2018 (Australian Aluminium Council, 2020).

There are six alumina refineries operating in Australia producing mostly smelter grade alumina for both the domestic and export markets according to the Australian Aluminium Council (2020):

- Pinjarra (Western Australia) – Alcoa
- Worsley (Western Australia) – South32
- Queensland Alumina Ltd (QAL) (Queensland) – Rio Tinto, Rusal
- Yarwun (Queensland) – Rio Tinto
- Wagerup (Western Australia) – Alcoa
- Kwinana (Western Australia) – Alcoa.

3. GHG EMISSION SOURCES

3.1 Bauxite mining

3.1.1 Bauxite mining methodology

Bauxite mining generally comprises a five steps process:

1. **Preparation of the mining area** – includes undertaking pre-mining surveys, environmental assessments and establishing environmental controls.
2. **Bauxite mining** – overburden is removed via scrapers and small excavators or by blasting, depending on the depth of the resource. The bauxite is then mined using excavators or loaders to load the bauxite onto haul trucks for transport to the crusher. Several pits are usually mined simultaneously to produce a consistent grade of ore.
3. **Crushing** – a crusher is used to break the ore into a smaller size suitable for transport (approximately 7.5 centimetres (cm) or less in diameter).
4. **Ore transport** – the crushed bauxite is transported via conveyor belts and railway systems to either the refinery or shipping terminal.
5. **Rehabilitation** – following the completion of mining activities the site is rehabilitated (Australian Aluminium Council, 2020).

3.1.2 Scope 1 and 2 GHG emission sources

GHG emissions associated with bauxite mining include CO_2, methane (CH_4), nitrous oxide (N_2O) and sulphur hexafluoride (SF_6).

The largest contributor of Scope 1 GHG emissions from bauxite mining results from energy use (predominantly diesel) by mobile equipment and fixed plant for mining activities and haulage of ore and overburden materials generally contributing around 95% of the total GHG emissions (International Aluminium Institute, 2018). Minor amounts of Scope 1 GHG emissions are associated with sewerage and domestic wastes, leakage from switchgear in the form of SF_6 gas and organic material decomposition following progressive vegetation clearing.

Electricity (Scope 2) is used in the operation of the bauxite crushing facilities and other ancillary facilities (including crib rooms and mining related administration blocks). Most electricity used at the BBM is sourced from the alumina refinery, with minor amounts sourced from the grid. Electricity generation for the proposal is through the burning of coal, diesel, fuel oil, natural gas, biofuels (wood) at the refinery, and/or purchased electricity from the grid i.e. the Southwest Interconnected System (SWIS).

3.1.3 Factors influencing GHG emissions intensities

The bauxite mining process can differ significantly depending on the location and size of the deposit, local topography and geology, location and specifics of the sizing and stockpiling facilities and support operations, among other factors. Factors influencing the GHG emissions intensity from bauxite mining operations include:

- Vegetation clearing which can increase GHG emissions and is typically undertaken at the commencement of operations in a new area
- Depth to the bauxite resource
- Type and quantities of mobile equipment used
- Length of haul routes between the mining area, crusher and export facilities
- Energy source used for onsite electricity generation (coal, gas, oil etc.)

3.2 Alumina Refinery

3.2.1 Alumina refinery methodology

Aluminium does not occur as a metal but must first be refined from bauxite into alumina. Approximately two tonnes of alumina are required to produce one tonne of aluminium (Australian Aluminium Council, 2020).

The Bayer process is the primary process by which alumina is extracted from bauxite and involves four steps:

1. **Digestion** – bauxite is finely ground in mills, then mixed with a recycled caustic soda solution and steam in digester vessels operating at high temperature and pressure. This dissolves the alumina content of the bauxite. The solution is then cooled in a series of flash tanks.
2. **Clarification** – the impurities which remain undissolved are allowed to settle as a fine mud in thickening tanks. After several washing stages to recover caustic soda, the residue is pumped to storage dams. The solution of alumina in caustic soda is further clarified by filtration.
3. **Preparation** – alumina crystals are recovered from the caustic solution by mechanically stirring the solution in open-top tanks. Crystal growth is assisted by seeding with previously precipitated alumina.
4. **Calcination** – the precipitated material (called hydrate) is washed and dried at temperatures exceeding 1000 degrees Celsius (°C). This forms the dry white anhydrous aluminium oxide powder (alumina) which is cooled and conveyed to storage. The caustic soda is recovered and returned to the start of the process and used again (Australian Aluminium Council, 2020).

3.2.2 Scope 1 and 2 GHG emission sources

GHG emissions associated with alumina refineries include CO_2, CH_4, N_2O, SF_6 and hydrofluorocarbons (HFC).

Most of the Scope 1 GHG emissions associated with alumina refining are from the combustion of fossil fuels by mobile equipment and fixed plant. Other major sources of Scope 1 emissions include energy production (steam and electricity) for onsite consumption through the combustion of fuels and diesel use in transportation activities. Minor amounts of Scope 1 GHG emissions are also associated with sewerage and domestic wastes, leakage from switchgear in the form of HFC and SF_6 gas.

Scope 2 are associated with the consumption of electricity. Refining bauxite into alumina requires significant energy consumption for the generation of heat and steam. Coal and natural gas are consumed in the generation of steam for onsite consumption and the calcination process.

Figure 3-1 displays the estimated fuel consumption makeup for alumina refineries across the world as reported by the IAI. Figure 3-1 shows that the type and proportions of fuels used in alumina refineries varies significantly on a regional scale. The primary fuel source used in Australia (Oceania) is gas, proportioning approximately 68% of the total fuel makeup. Coal is the second largest fuel source contributing around 23%. The Worsley Alumina Refinery uses coal as its primary fuel resource.

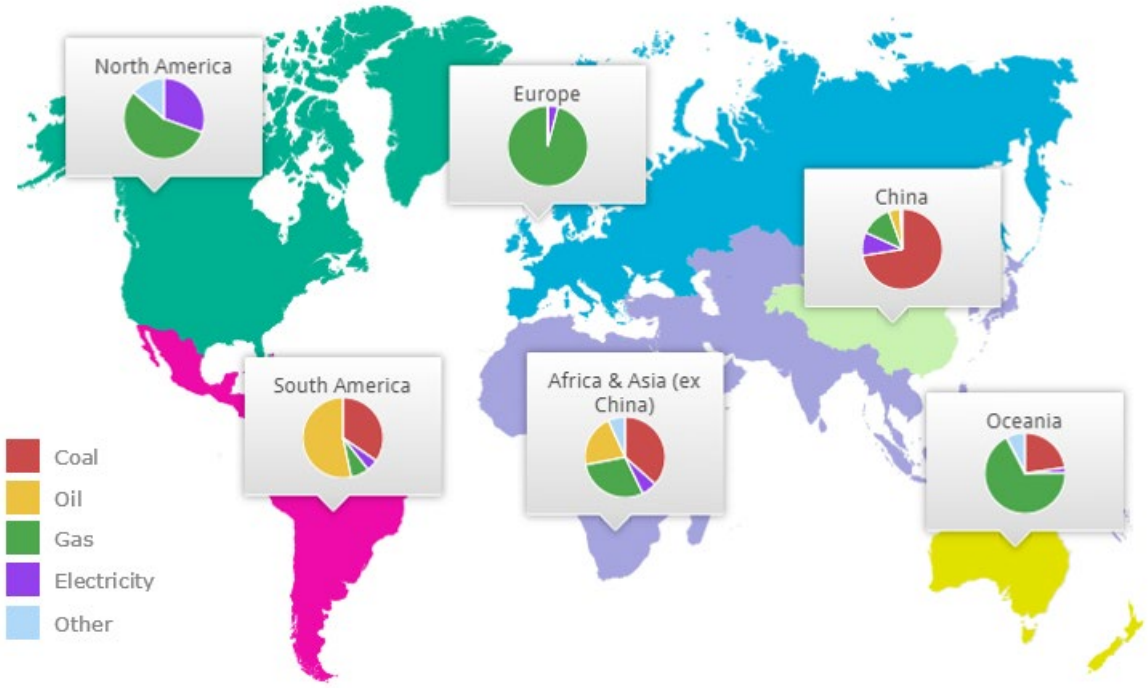

Figure 3-1: Global alumina refining fuel consumption makeup (2019)

Source: (International Aluminium Institute, 2020)

3.2.3 Factors influencing GHG emissions intensities

Factors influencing the GHG emissions intensity from alumina refinery operations include:

- Type and quantities of mobile equipment used
- Energy source used for onsite electricity generation (coal, gas, oil etc.)
- Quality of bauxite input
- Technology used in the Bayer process.

4. GHG BENCHMARKING

4.1 Western Australian context

4.1.1 Environmental Protection Agency Environmental Factor Guideline

The WA EPA *Environmental Factor Guideline – Greenhouse Gas Emissions* (Environmental Protection Agency, 2020) provides a guideline for the consideration of GHG emissions in the environmental impact assessment (EIA) process. The guideline establishes that GHG emissions from a proposal will generally be assessed where they exceed 100,000 tonnes per annum (tpa) of CO_2-e Scope 1 emissions. For proposals that exceed this threshold and require assessment, the EPA may request the following information:

- credible estimates of scope 1, scope 2 and scope 3 GHG emissions (annual and total) over the life of a proposal
- a breakdown of GHG emissions by source inclusive of, but not limited to, stationary energy, fugitives, transport, and emissions associated with changes to land use
- projected emissions intensity (emissions per unit of production) for the proposal and benchmarking against other comparable projects

4.1.2 GHG emissions in Western Australia

Total Scope 1 emissions for Western Australia in 2018 were 91.5 Mt CO_2-e. In 2018-19, oil and gas extraction continued to be the highest emitting industry in Western Australia, whilst metal ore mining was the third highest emitting industry (Clean Energy Regulator, 2020).

4.2 Australian context

4.2.1 NGER Scheme and the Safeguard Mechanism

The Clean Energy Regulator (CER) was established on 2 April 2012 as an independent statutory authority by the *Clean Energy Regulator Act 2011*. The *National Greenhouse and Energy Reporting Act 2007* (NGER Act) establishes the legislative framework for the NGER Scheme, a national framework for reporting GHG emissions, GHG and energy consumption and production by corporations in Australia.

The "Safeguard Mechanism" is administered through the NGER scheme and, together with the reporting obligations under the NGER Act, provides a framework for Australia's largest emitters to measure, report and manage their emissions. It does this by encouraging large facilities, whose net emissions exceed the Safeguard threshold, to keep their emissions at or below emissions baselines set by the CER. The Safeguard mechanism applies to those facilities with scope 1 emissions of more than 100,000 t CO_2e/annum.

Australian corporations that meet the following facility thresholds must report their emissions and energy information annually under the NGER scheme:

- 25,000 t or more of GHG (CO_2e) (scope 1 and scope 2 emissions)
- Production of 100 terajoules (TJ) or more of energy, or
- Consumption of 100 TJ or more of energy.

Bauxite mines and alumina refineries generally meet these facility threshold limits and therefore are required to report GHG emissions, energy production, energy consumption under the NGER scheme. Each year the CER releases the *Technical Guidelines for Reporting Facilities* and the Australian National Greenhouse Accounts Factors used.

Data published under the NGER indicates that the total reported emissions for all corporations in the 2018/19 financial year was 338 Mt CO_2e of scope 1 GHG emissions and 88 Mt CO_2e of scope 2 GHG emissions (Clean Energy Regulator, 2020).

The Commonwealth Department of Industry, Science, Energy and Resources (DISER) published the *Safeguard Mechanism document: Prescribed production variables and default emissions intensities* (the 'Safeguard Mechanism Document') in October 2020. The default emissions intensity for bauxite mining is 0.00401 t CO_2-e/t bauxite product (DISER, 2020). The default emissions intensity for alumina refineries is 0.545 t CO_2-e/t of alumina and alumina equivalent t of alumina trihydrate product (DISER, 2020).

4.2.2 Bauxite mining

Limited data is available on the total GHG emissions from the Australian bauxite mining sector. A recent study (Michael Tost, 2018) calculated the average CO_2 emissions from bauxite mining to be on average 0.0049 t CO_2/t bauxite produced. Note this value does not include CH_4, N_2O or SF_6 emissions that would also contribute to the total GHG emissions.

Nation-wide bauxite production data is reported by the Australian Aluminium Council from 2000 to 2019. Table 4-2 provides a summary of the reported data for the production from 2017 to 2019.

Table 4-1: Production data for Australian bauxite mines

Element	Units	2019	2018	2017	Average
Alumina production	t	102,000,000	96,000,000	95,000,000	97,670,000

Source: (Australian Aluminium Council, 2020)

4.2.3 Alumina refining

The Australian Aluminium Council has reported Sustainability Data from 2000 to 2019 for alumina refineries. Table 4-2 provides a summary of the reported data for the production, total GHG emissions and GHG emissions intensities for all Australian alumina refineries from 2017 to 2019. The average GHG emissions intensity over the 2017 to 2019 period for Scope 1 and Scope 2 emissions is 0.71 t CO_2-e/t alumina produced.

Table 4-2: Production, GHG emissions and GHG emissions intensities for Australian alumina refineries

Element	Units	2019	2018	2017	Average
Alumina production	t	20,480,000	20,310,000	20,710,000	20,500,000
Total GHG emissions	t	1,432,000	1,452,000	1,465,000	1,450,000
Emissions intensity	t CO_2-e/t	0.70	0.71	0.71	0.71

Source: (Australian Aluminium Council, 2020)

4.3 Global context

4.3.1 Bauxite mining

As bauxite mining consumes a relatively small amount of energy, and consequently has low GHG compared to other parts of the aluminium life cycle, there is limited data on global GHG emission intensities. The global average energy consumption is less than 100 Megajoules (MJ) per tonne of bauxite, with each tonne of bauxite having to be transported on average 50 km from the point of extraction to the shipping point or local refinery stockpile (International Aluminium Institute, 2018).

Diesel fuel and fuel oil combustion provide most (approximately 95%) of the energy required to extract and haul the mined ore. (International Aluminium Institute, 2018).

4.3.2 Alumina refining

There is limited data available on the GHG emissions intensities for alumina refining. One study (Alcoa of Australia Limited, 2020) reports that the global weighted average for Scope 1 and 2 emissions from alumina refining in 2018 was 1.345 t CO_2-e/t alumina.

Data on global intensities for alumina refineries is generally assessed based on energy intensity in MJ/t. Figure 4-1 shows the estimated energy intensities for alumina refining globally in MJ/t alumina reported by the IAI. In general, energy intensities for alumina production have decreased in recent years with the exception of Europe and Africa and Asia (excluding China). In 2019 Australia (Oceania) ranked slightly lower than the global average energy intensity (10,736 MJ/t alumina) at 10,417 MJ/t alumina. Europe and Africa and Asia (excluding China) are the highest energy intensive groups, requiring 13,456 and 12,852 MJ/t alumina respectively in 2019. The lowest energy intensive groups are North America and South America reporting around 8,900 MJ/t alumina in 2019 (International Aluminium Institute, 2020).

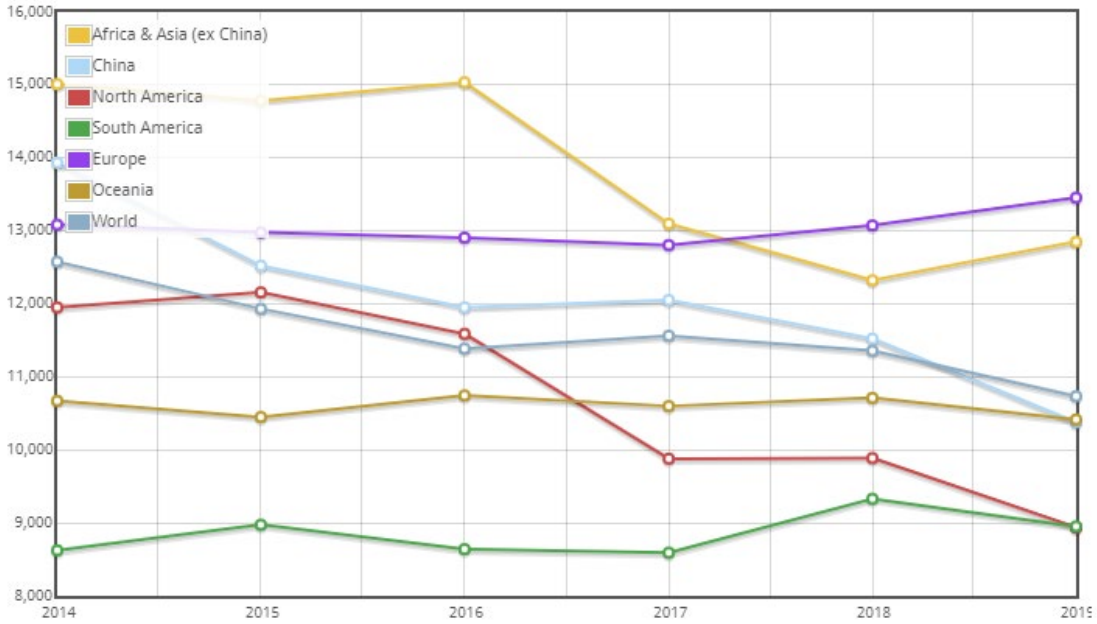

Figure 4-1: Global alumina refining energy intensities (MJ/t alumina) from 2014 to 2019

Source: (International Aluminium Institute, 2020)

5. WORSLEY'S EMISSIONS PROFILE

Table 5-1 provides a summary of the GHG emission and the GHG emissions intensity estimates for the mine and the refinery. Contextualisation of Worsley's emissions profile is provided in Section 7.

Input data to the GHG emission estimations were sourced directly from South32 and have not been verified by Ramboll. Safeguard forecasting data has been used in the assessment. The financial year (FY) 2022 was selected as the representative baseline year for a conservative approach.

The GHG emissions estimates and GHG emissions intensity presented in Table 5-1 are based on the following:

- The annual mine production rates for the revised proposal are proposed to remain within that currently approved at 18.8 Mt of bauxite.
- The annual refinery production rates for the revised proposal are proposed to remain within that currently approved at a maximum of 4.7 Mt of alumina
- Energy consumption from fuels through the powerhouse is back calculated from the amount of high-pressure steam that is produced, along with a number of other inputs such as boiler efficiencies, steam enthalpies and fuel energy content.
- The split for energy consumption (Scope 1) between the mine and the refinery is based on the amount of steam used in the refinery and the relative ratio of power consumed at both the refinery and the mine.
- Scope 2 emissions are attributed to the mine are calculated as a portion of imported electricity using the same methodology for the energy consumption split.
- It is noted that these estimates exclude sequestration of emissions by mine rehabilitation.
- GHG emissions intensities for the mine are reported to five decimal places whilst GHG emissions intensity for the refinery are reported to three decimal places for consistency with the Safeguard Mechanism Document.

Table 5-1: GHG emission estimates and intensities for Worsley's mine and refinery

Element	Units	Mine Forecast FY22	Refinery Forecast FY22
Production[1]	tpa	18,800,000	4,600,000
GHG EMISSIONS			
Total Scope 1[1]	t CO2-e/annum	103,712	3,615,065
Total Scope 2[1]	t CO2-e/annum	769	40,287
Total Scope 1 + Scope 2[1]	t CO2-e/annum	104,481	3,655,352
GHG EMISSIONS INTENSITY			
Scope 1	t CO2-e/t product	0.00552	0.786
Scope 1 + Scope 2	t CO2-e/t product	0.00556	0.795

[1] (South32, 2020)

6. OTHER FACILITIES

A literature review to identify comparable facilities to the Worsley Bauxite-Alumina operation, in a State, Australian and international context was undertaken. Table 6-1 provides a summary of the facilities identified and the average emissions intensity calculated for the comparable facilities. Appendix 1 provides the complete data set and breakdown for facilities included in this benchmarking study including refences for sources of information.

The facilities presented in Table 6-1 were selected based on the availability of public data. The following limitations are noted:

- GHG emissions data was obtained from Safeguard reporting data, mining company websites and reports.
- The GHG emissions data was largely available for Scope 1 emissions only.
- Average GHG emission intensities were calculated using the most recent three years of data where available.
- Data for the bauxite mines located in Guinea is based on an average of the Sangaredi Mines owned by Compagnie des Bauxites de Guinée (CBG). This includes Widder, Pacioni and Bocoum.
- Public data was not available for China and Russia who generally have higher GHG emissions intensities (Paraskevas, 2016).
- GHG emissions intensities for the mine are reported to five decimal places whilst GHG emissions intensity for the refinery are reported to three decimal places for consistency with the Safeguard Mechanism Document.

Table 6-1: Comparable facilities GHG emissions intensities

Facility name	Location	Average emissions intensity (t CO_2-e/t)
BAUXITE MINES		
Alcoa - Huntly Bauxite Mine	WA, Australia	0.00600
Alco - Willowdale Bauxite Mine	WA, Australia	0.00565
Rio Tinto (QAL) - Weipa Operation	QLD, Australia	0.00737
Rio Tinto - Gove Bauxite Mine	NT, Australia	0.01102
CBG - Sangaredi Mines	Guinea	0.02000
Average all bauxite mines	**All**	**0.01001**
Average all Australian bauxite mines	**Australia**	**0.00751**
ALUMINA REFINERIES		
Alcoa - Pinjarra Refinery	WA, Australia	0.598
Alcoa - Kwinana Refinery	WA, Australia	0.589
Alcoa - Wagerup Refinery	WA, Australia	0.544
Rio Tinto / RUSAL - QAL	QLD, Australia	0.890
Rio Tinto - Yarwun Refinery	QLD, Australia	0.695
Hydro - Alunorte	Brazil	0.730

Facility name	Location	Average emissions intensity (t CO_2-e/t)
Alcoa - San Ciprian Alumina Refinery	Spain	0.429
RUSAL - Aughinish Alumina	Ireland	0.645
Rio Tinto - Jonquière (Vaudreuil) refinery	Canada	0.340
RUSAL - Friguia Alumina Refinery	Guinea	1.690
Alcoa - Point Comfort Alumina Refinery	United States	0.408
Noranda Alumina Refinery	United States	0.666
Average all alumina refineries	**All**	**0.685**
Average all Australian alumina refineries	**Australia**	**0.663**

7. RESULTS AND DISCUSSION

7.1 GHG emissions intensity comparison

7.1.1 Benchmarking results summary

A summary of the benchmarking results is presented in Table 7-1.

Table 7-1: GHG benchmarking results summary

Element	Scope	Average emissions intensity (t CO_2-e/t)	
		Mine	Refinery
Worsley	Scope 1	0.00552	0.786
Australia default emissions intensity[1]	Scope 1	0.00401	0.545
Other facilities - all	Scope 1	0.01001	0.685
Other facilities - Australia	Scope 1	0.00751	0.663
Worsley's GHG emissions intensity	Scope 1 + 2	0.00556	0.795
Global average refinery emissions[2]	Scope 1 + 2	-	1.345
Australian average refinery emissions[3]	Scope 1 + 2	-	0.71

[1](DISER, 2020)

[2] (Alcoa of Australia Limited, 2020)

[3] (Australian Aluminium Council, 2020)

7.1.2 Other facilities

7.1.2.1 Bauxite mines

Figure 7-1 shows the average GHG emissions intensities calculated for scope 1 for Worsley bauxite mine in comparison to the other bauxite mining facilities considered in the study. The GHG emissions intensity for the Worsley bauxite mine is 0.00552 t CO_2e/t product based on the benchmark year selected.

The Worsley bauxite mine has the lowest GHG emissions intensity for scope 1 across those considered in this study. The Worsley bauxite mine is 0.00449 t CO_2e/t product (44.9%) lower than the average GHG emissions intensity (0.01001 t CO_2e/t product) for scope 1 emissions from all facilities considered in this study considered in this study. For facilities located only in Australia, the average GHG emissions intensity is 0.00751 t CO_2e/t product, which is 0.00199 t CO_2e/t product (26.5%) higher than the GHG emissions intensity for the Worsley bauxite mine.

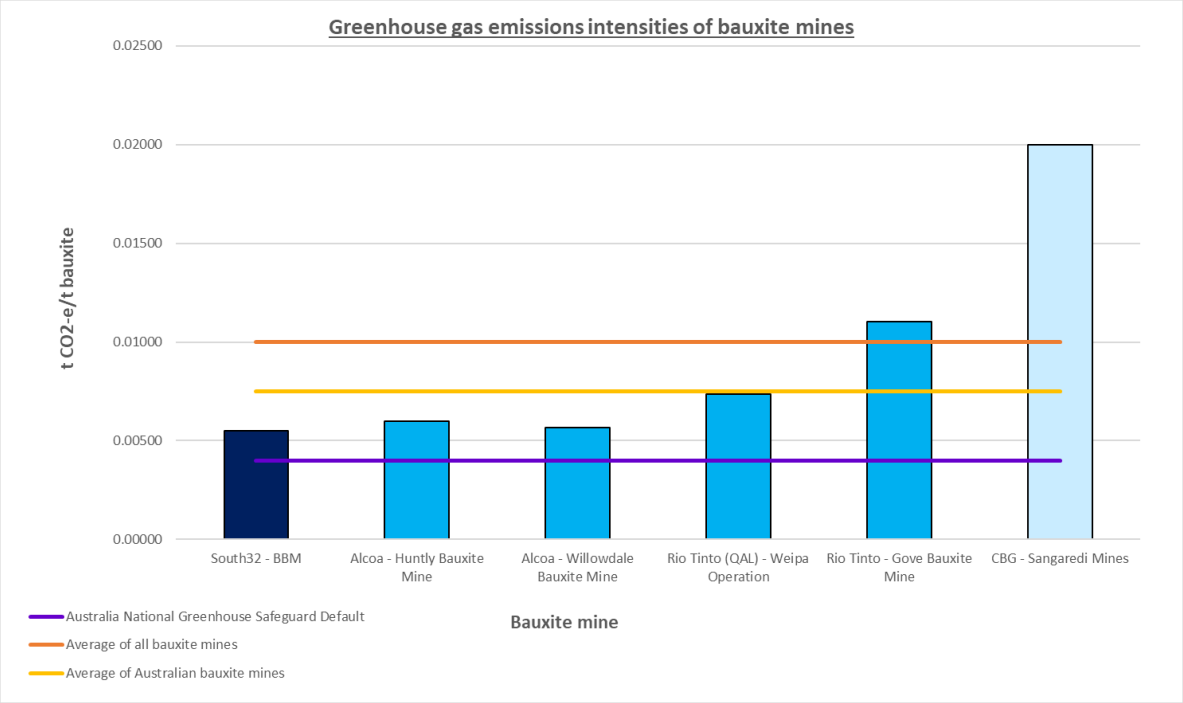

Figure 7-1: GHG emissions intensities for the Worsley bauxite mine and comparable facilities

7.1.2.2 Alumina refineries

Figure 7-1 shows the GHG emissions intensities calculated for scope 1 for the Worsley alumina refinery in comparison to the other refinery facilities considered in the study. The GHG emissions intensity for the Worsley alumina refinery is 0.786 t CO_2e/t product based on the benchmark year selected.

The Worsley alumina refinery is 0.101 t CO_2e/t product (14.7%) higher than the average GHG emissions intensity (0.685 t CO_2e/t product) for scope 1 emissions from all facilities considered in this study. For facilities located only in Australia, the average GHG emissions intensity is 0.663 t CO_2e/t product, which is 0.123 t CO_2e/t product (15.6%) lower than the GHG emissions intensity for the Worsley alumina facility. Compared with the global average GHG emissions intensity (1.345 t CO_2e/t product), the GHG intensity from the Worsley alumina refinery is 0.55 t CO_2e/t product (41.6%) lower.

This disparity in GHG emissions intensities across different facilities assessed in this study is likely associated with the fuel types used in the refining process. The majority of refineries studied both within Australia and externally use natural gas in the refining process (see Appendix 1). The average GHG emissions intensity for refineries using natural gas is 0.572 t CO_2e/t product. The refinery with the lowest emissions intensity (0.340 t CO_2e/t product), the Vaudreuill refinery in Canada utilises hydroelectric power. The Rio Tinto / RUSAL – QAL refinery in Gladstone and other refineries in Guinea similar to the Worsley refinery utilise coal to generate the power and steam at the refinery. These facilities have an average emissions intensity of 1.290 t CO_2e/t product, which is 0.504 t CO_2e/t product (64.1%) higher than Worsley. Whilst facility specific data was not able to be obtained from refineries China and Russia, it is understood that coal is also used extensively at these locations and is considered to be one of the main drivers of the elevated global average. When compared with facilities using similar fuel types (i.e. Rio Tinto / RUSAL - QAL and Guinea refineries) the Worsley refinery is considered to have one of the lowest GHG emissions intensities and therefore be more energy efficient (refer to Figure 7-2).

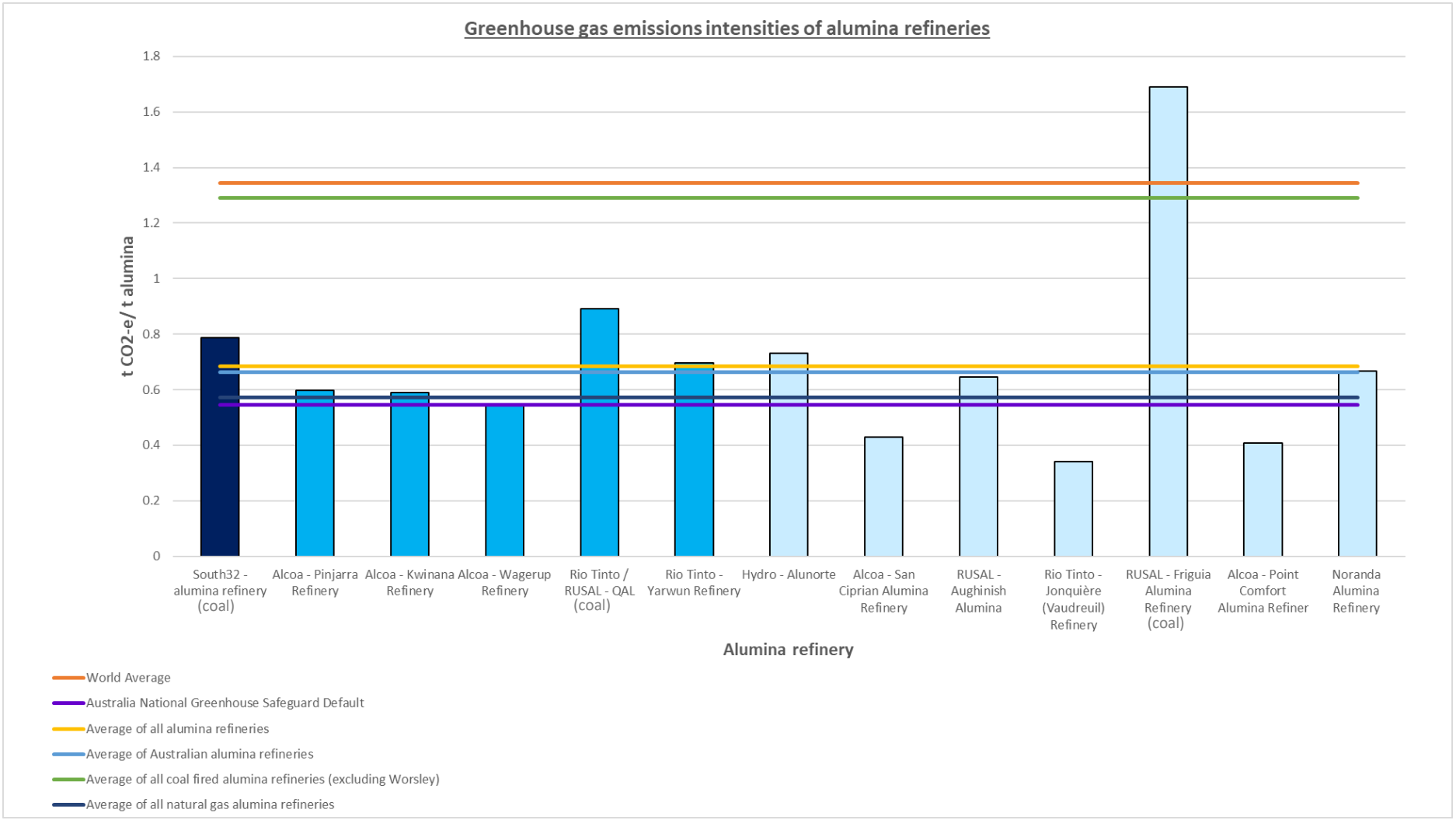

Figure 7-2: GHG emissions intensities for the Worsley Alumina refinery and comparable facilities

7.1.3 Western Australia

The proposal exceeds the threshold of 100,000 tpa of CO_2-e Scope 1 emissions established by the WA EPA *Environmental Factor Guideline – Greenhouse Gas Emissions* (Environmental Protection Agency, 2020) and therefore requires consideration in the EIA process.

The total Scope 1 GHG emissions from the Worsley Bauxite-Alumina operation are estimated to be 3,718,777 t CO_2-e per year based on the selected benchmarking year (FY22). This makes up around 4.06% of the total annual Scope 1 emissions for Western Australia based on the 2018 reported emissions of 91,500,000 t CO_2-e.

7.1.4 Australia

The estimated GHG emissions intensity for the Worsley bauxite mining operation is 0.00556 t CO_2e/t bauxite. This is 0.00151 t CO_2e/t bauxite (38%) higher than the default GHG emissions intensity for bauxite mining of 0.00401 t CO_2-e/t bauxite product established under the Safeguard Mechanism Document.

The estimated GHG emissions intensity for the Worsley alumina refinery is 0.795 t CO_2e/t alumina. This is 0.241 t CO_2e/t alumina (44.2%) higher than the default GHG emissions intensity for alumina refineries of 0.545 t CO_2-e/t alumina established under the Safeguard Mechanism Document.

The Australian Aluminium Council reports the average GHG emissions intensity for Australian alumina refineries over the 2017 to 2019 period for Scope 1 and Scope 2 emissions as 0.71 t CO_2-e/t alumina. This is 0.085 t CO_2-e/t alumina (9.7%) lower than the Worsley alumina refinery.

The total Scope 1 and Scope 2 GHG emissions from the Worsley Bauxite-Alumina operation are estimated to be 3,759,833 t CO_2-e per year based on the selected benchmarking year (FY22). This makes up around 0.88% of the total annual Scope 1 and Scope 2 emissions for Australia based on the 2018/19 reported emissions of 426,000,000 t CO_2e for all corporations under the NGER Scheme.

7.1.5 Global

The majority of benchmarking analyses and life-cycle assessments relating to the alumina industry generally relate to alumina production and do not provide a holistic assessment that includes bauxite mining.

One study (Alcoa of Australia Limited, 2020) reports that the global weighted average for Scope 1 and Scope 2 emissions from alumina refining in 2018 was 1.345 t CO_2-e/t alumina. This is 0.550 t CO_2e/t higher than the estimated GHG emissions intensity for the Worsley alumina refinery. This is likely due to the exclusion of countries such as China and Russia in the dataset, who generally have higher emission intensities (Paraskevas, 2016). Public data could not be located for these countries to include in the benchmarking study.

8. CONCLUSION

The benchmarking exercise identified that the Worsley bauxite mine has the lowest GHG emissions intensity for scope 1 across those considered in this study. The Worsley bauxite mine is 0.00449 t CO_2e/t product (44.9%) lower than the average GHG emissions intensity (0.01001 t CO_2e/t product) for scope 1 across those considered in this study. For facilities located only in Australia, the average GHG emissions intensity is 0.00751 t CO_2e/t product, which is 0.00199 t CO_2e/t product (26.5%) higher than the GHG emissions intensity for the Worsley bauxite mine.

The GHG emission intensity for the Worsley alumina refinery is slightly higher than the average emissions intensity for scope 1 across those facilities considered in this study and in comparison to the Australian facilities only. The Worsley alumina refinery is 0.101 t CO_2e/t product (14.7%) higher than the average GHG emissions intensity (0.685 t CO_2e/t product) for scope 1 emissions from all facilities considered in this study. For facilities located only in Australia, the average GHG emissions intensity is 0.663 t CO_2e/t product, which is 0.123 t CO_2e/t product (15.6%) lower than the GHG emissions intensity for the Worsley alumina facility. Compared with the global average GHG emissions intensity, the GHG intensity from the Worsley alumina refinery is 0.55 t CO_2e/t product (41.6%) lower.

This disparity in GHG emissions intensities across different facilities assessed in this study is likely associated with the fuel types used in the refining process. The majority of refineries studied both within Australia and externally use natural gas in the refining process (see Appendix 1). The average GHG emissions intensity for refineries using natural gas is 0.572 t CO_2e/t product. The refinery with the lowest emissions intensity (0.340 t CO_2e/t product), the Vaudreuill refinery in Canada utilises hydroelectric power. The Rio Tinto / RUSAL – QAL refinery in Gladstone and other refineries in Guinea similar to the Worsley refinery utilise coal to generate the power and steam at the refinery. These facilities have an average emissions intensity of 1.290 t CO_2e/t product, which is 0.504 t CO_2e/t product (64.1%) higher than Worsley. Whilst facility specific data was not able to be obtained from refineries China and Russia, it is understood that coal is also used extensively at these locations and is considered to be one of the main drivers of the elevated global average. When compared with facilities using similar fuel types (i.e. Rio Tinto / RUSAL - QAL and Guinea refineries) the Worsley refinery is considered to have one of the lowest GHG emissions intensities and therefore be more energy efficient.

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APPENDIX 1
OTHER FACILITIES DATA

Facility	Location	Year	Production throughput (tpa)	GHG emissions (t CO_2-e)	GHG emissions intensity (t CO_2-e /t)	Comments
BAUXITE MINES						
Alcoa - Huntly Bauxite Mine [1]	Western Australia, Australia	2019	27,000,000	162,000	0.00600	
Alcoa - Willowdale Bauxite Mine [2]	Western Australia, Australia	2019	10,000,000	56,470	0.00565	
Rio Tinto (QAL) - Weipa Operation [3]	Queensland, Australia	2018-2019	32,924,000	204,705	0.00622	
		2017-2018	30,667,000	254,961	0.00831	
		2016-2017	30,163,000	228,733	0.00758	
		Average 2016-2019	**31,251,333**	**229,466**	**0.00737**	
Rio Tinto - Gove Bauxite Mine	Northern Territory, Australia	2018-2019	12,371,000	129,407	0.01046	
		2017-2018	11,871,000	128,172	0.01080	
		2016-2017	10,146,000	119,736	0.01180	
		Average 2016-2019	**11,462,667**	**125,772**	**0.01102**	
Compagnie des Bauxites de Guinée (CBG) - Sangaredi Mines	Guinea [4]	2019	13,701,000	274,020	0.02000	Owned: Guinean state – 49%; Halco partnership – 51% (average emissions for Bauxite mines in Guinea)
		2018	13,039,000	260,780	0.02000	
		2017	15,409,000	308,180	0.02000	
		Average 2017-2019	**14,049,667**	**280,993**	**0.02000**	
Average all bauxite mines	**All bauxite mines**		**18,752,733**	**170,940**	**0.01001**	
Average all Australian bauxite mines	**Australia only**		**19,928,500**	**143,427**	**0.00751**	
ALUMINA REFINIERIES						
Alcoa - Pinjarra Refinery [5;6]	Western Australia, Australia	2018-2019	4,700,000	2,834,000	0.603	Natural gas-fired (thermal)[7]
		2017-2018	4,700,000	2,808,963	0.598	
		2016-2017	4,700,000	2,789,659	0.594	
		Average 2016-2019	**4,700,000**	**2,810,874**	**0.598**	
Alcoa - Kwinana Refinery	Western Australia, Australia	2018-2019	2,190,000	1,258,124	0.574	Natural gas-fired (thermal)
		2017-2018	2,190,000	1,250,831	0.571	
		2016-2017	2,190,000	1,282,994	0.620	
		Average 2016-2019	**2,190,000**	**1,263,983**	**0.589**	
Alcoa - Wagerup Refinery	Western Australia, Australia	2018-2019	2,555,000	1,380,208	0.540	Natural gas-fired (thermal)
		2017-2018	2,555,000	1,448,358	0.567	
		2016-2017	2,555,000	1,433,823	0.524	
		Average 2016-2019	**2,555,000**	**1,420,796**	**0.544**	
Rio Tinto / RUSAL - Queensland Alumina Ltd	Queensland, Australia	2018-2019	3,576,000	3,192,846	0.893	Coal power station (Gladstone)
		2017-2018	3,716,000	3,384,495	0.911	
		2016-2017	3,791,500	3,284,264	0.866	
		Average 2016-2019	**3,694,500**	**3,287,202**	**0.890**	
Rio Tinto - Yarwun Refinery	Queensland, Australia	2018-2019	3,097,000	2,119,012	0.684	Cogeneration natural gas (turbine) and heat recovery steam generator
		2017-2018	3,153,000	2,218,636	0.704	
		2016-2017	3,190,000	2,227,172	0.698	
		Average 2016-2019	**3,146,667**	**2,188,273**	**0.695**	
Hydro - Alunorte [8]	Brazil	2019	4,487,000	3,185,770	0.710	Fuel oil powered
		2018	3,712,000	2,932,480	0.790	
		2017	6,397,000	4,413,930	0.690	

Facility	Location	Year	Production throughput (tpa)	GHG emissions (t CO_2-e)	GHG emissions intensity (t CO_2-e /t)	Comments
		Average 2017-2019	**4,865,333**	**3,510,727**	**0.730**	
Alcoa - San Ciprian Alumina Refinery	Spain [9]	2017	1,500,000	647,000	0.431	Natural gas-fired (thermal) (since 2015 when it switched from fuel oil)
		2016	1,500,000	630,000	0.420	
		2015	1,500,000	652,000	0.435	
		Average 2017-2019	**1,500,000**	**643,000**	**0.429**	
RUSAL - Aughinish Alumina [10]	Ireland	2019	1,900,000	1,200,000	0.632	Natural Gas Combined Heat & Power Plant (CHP Plant)
		2018	1,900,000	-	-	
		2017	1,900,000	1,250,000	0.658	
		Average 2017-2019	**1,900,000**	**1,225,000**	**0.645**	
Rio Tinto - Jonquière (Vaudreuil) refinery	Canada [11]	2018	1,444,000	433,331	0.300	Hydroelectric power
		2017	1,448,000	521,498	0.360	
		2016	1,452,000	521,876	0.359	
		Average 2016-2018	**1,448,000**	**492,235**	**0.340**	
RUSAL - Friguia Alumina Refinery	Guinea [4]	**Average 2008-2018**	**600,000**	**1,014,000**	**1.690**	(average emissions for Alumina Refineries in Guinea)
Alcoa - Point Comfort Alumina Refinery (closed 2015)	United States [12]	2015	2,300,000	959,991	0.417	Natural gas-fired (thermal)
		2014	2,300,000	935,628	0.407	
		2013	2,300,000	922,339	0.401	
		Average 2013-2015	**2,300,000**	**939,319**	**0.408**	
Noranda Alumina Refinery [13]	United States [12]	2018	1,200,000	780,326	0.650	Cogeneration natural gas (turbine)
		2017	1,200,000	844,348	0.704	
		2016	1,200,000	772,428	0.644	
		Average 2016-2018	**1,200,000**	**799,034**	**0.666**	
Average all alumina refineries	**All alumina refineries**		**2,508,292**	**1,632,870**	**0.685**	
Average all Australian alumina refineries	**Australia only**		**3,257,233**	**2,194,226**	**0.663**	

Table Notes:

[1] Alcoa 2020, Environmental Referral Supporting Document

[2] Emissions per t bauxite mined sourced from Alcoa 2015, 2014-2015 Sustainability Highlights Report

[3] Rio Tinto Production throughputs and alumina refinery power sourced from Rio Tinto 2019 Annual Report

[4] Guinea average emissions sourced from 2008-2018 data in Widder, Pacioni and Bocoum 2019, Sustainably Growing Guinea's Bauxite-Aluminum Industry

[5] Nameplate Capacity reported for Alcoa facilities as production values for each specific facility were not reported (Alcoa 2019, Alcoa 2019 Annual Report)

[6] The baseline emissions for the Alinta Pinjarra Generation Facility were added to the reported Pinjarra Refinery emissions to get total emissions from the Pinjarra facility.

[7] Alcoa Refineries power type sourced from: https://www.aluminalimited.com/energy/

[8] Norsk Hydro Data sourced from Hydro 2019 Annual Report

[9] European refinery (San Ciprian and Aughinish) emissions sourced from the EU Greenhouse Gas Monitoring Mechanism, National greenhouse gas inventories

[10] Rusal facility production throughput and information sourced from https://rusal.ru/en/about/geography/

[11] Canada Facility emissions data sourced from Canada's greenhouse gas inventory

[12] USA emissions data sourced from US EPA Greenhouse Gas Reporting Program (GHGRP)

[13] https://newdayal.com/noranda-alumina

Appendix B Summary of Proposed Management Actions

Management Action	Description	Timing	Monitoring and Reporting
MA1 – Establish Interim Emission Reduction Targets (Section 4.1.1)	To establish interim reduction targets over five yearly increments to drive performance over the indicative duration of the proposal: • 8% reduction by EOFY26[9] • 20% reduction by EOFY31 • 40% reduction by EOFY36. The targets will apply to the net operational emissions (Scope 1 and Scope 2) inclusive of both the BBM and Refinery, with 3.75 Mt CO2e used as the baseline (aligned with existing MS719 authorised emissions limit). They will be adjusted to account for the net emissions balance between import and export electricity between the Refinery and the SWIS.	Commencement of GHGMP	Emissions are monitored and reported internally on a monthly basis and reported annually under regulatory (e.g. NGER Act) and voluntary schemes (e.g. TCFD), and in accordance with the requirements set out in Section 4.3 of the GHGMP. The GHG emissions and associated reductions will be independently verified by an auditor accredited under the NGER Act. Performance against the goals and targets, and the details of the next interim reduction target will be documented as part of the five-yearly review of the GHGMP outlined in Section 4.3 of the GHGMP.
MA2 – Mitigation Measures (Section 4.1.2)	Build on existing studies and emission reduction activities to develop and implement reasonable and practicable decarbonisation initiatives that are intended to achieve the interim reduction targets. Evaluation of new and existing projects against a number of criteria including safety, technical performance, operability, emissions reduction, maturity, scale, economic return and time required to adapt to changes in process or energy efficiency technologies (including technology commercialisation).	Ongoing	Annual update on the status and maturity of studies and emission reduction activities included in the Worsley Alumina Annual Environmental Report, and as part of the five-yearly review of the GHGMP. This will include reporting on expected changes to the abatement potential of projects as they move through their respective study phases to confirm whether they are reasonable and practicable.
	Energy Efficiency (Section 4.1.2.1) • Mud Washing Study – new, high efficiency washers to reduce the amount of water and evaporation required, and associated consumption of coal generated steam. • Waste Heat to Digestion Study – modifications and upgrades to the Refinery to allow re-use of waste	Ongoing	Summary of study outcomes and progress through internal tollgates to be reported annually in the Worsley Alumina Annual Environmental Report.

[9] FYXX years are based on draft Revised Proposal submission and are subject to change in line with the Worsley Environmental Approval

Management Action	Description	Timing	Monitoring and Reporting
	heat to pre-heat incoming process streams and reduce the amount of required direct steam and associated consumption of coal. • Other – Facility 50 dilution reduction, calciner flue gas heat recovery, replacing steam ejectors with vacuum pumps.		
	Fuel Switching (Section 4.1.2.2) • Coal to Gas Conversion Study – displacing coal with natural gas (as a transitional fuel) as the primary fuel source to the coal and multi-fuel cogeneration boilers on site. • Biomass Execution– short-term complementary activity that utilises timber waste product (biomass) as a fuel source to reduce coal consumption. • Other – investigate and progress studies to achieve final state energy supply requirements (i.e. gas to lower carbon energy source).	Ongoing	Summary of study outcomes and progress through internal tollgates to be reported annually in the Worsley Alumina Annual Environmental Report.
	Long-term Studies and Future Technology (Section 4.1.2.3) • Renewables – studying renewable technologies that could support commercial deployment of renewable energy alternatives, such as hydrogen or electrification. • Industry Partnerships – leverage and accelerate our efforts by collaborating with other companies, industry groups and research organisations • Other – support low-carbon energy markets and policy to underpin decarbonisation of the south-west energy grid	Ongoing	Summary of study outcomes and progress through internal tollgates to be reported annually in the Worsley Alumina Annual Environmental Report.
	Carbon Offsets (Section 4.1.2.4)	Ongoing	Carbon offset acquisition strategies and retirement of offsets (if required) to be reported in Worsley Alumina

Management Action	Description	Timing	Monitoring and Reporting
	• As described in Section 4.1.2.4 of the GHGMP, and following application of the mitigation hierarchy, Worsley may seek to acquire and retire carbon offsets to meet the proposed interim targets and offset against residual and 'hard to abate' emissions where decarbonisation alternatives remain undeveloped, or not technically or economically feasible. • Options to acquire offsets include procurement, partnership and self-generation strategies and may provide additional co-benefits (e.g. environment or local communities).		Annual Environmental Report, and as part of the five-yearly review of the GHGMP.
MA3 – Adaptive Management, Monitoring and Review (Section 4.1.3)	Apply an adaptive management approach to enable Worsley Alumina to adapt and respond to changing circumstances, optimise the delivery of the proposed and future management actions, with an aspiration, where reasonable and practical, to out-perform and not just meet the interim reduction targets. Commit to annual reporting and five yearly reviews to monitor and review effectiveness of emission reduction measures.	Annually, with formal review of GHGMP every five years	Emissions are monitored and reported internally on a monthly basis and reported annually under regulatory (e.g. NGER Act) and voluntary schemes (e.g. TCFD), and in accordance with the requirements set out in Section 4.3 of the GHGMP. The emissions performance will be reviewed to monitor performance against the interim emissions reduction targets, review the effectiveness of GHG emission measures and adjust the approach to achieve the objectives of this plan. Outcomes of any reviews or updates to the management approach will be reported in the Worsley Alumina Annual Environment Report, and as part of the five-yearly review of the GHGMP.
MA4 – Just Transition Planning (Section 4.1.4)	Undertake a Just Transition Risk Assessment to better understand the potential risks and opportunities to people and communities through the energy transition. The outcomes of this work will inform South32's ongoing participation in the Collie Just Transition Working Group	Risk Assessment commenced in FY22. Ongoing implementation in collaboration with CJTWG	Findings of the Just Transition Risk Assessment and relevant activities of the Collie Just Transition Working Group to be reported in the Worsley Alumina Annual Environmental Report, and as part of the five-yearly review of the GHGMP.

Management Action	Description	Timing	Monitoring and Reporting
	(CJTWG) and implementation of the Just Transition Plan for Collie.		
MA5 – Addressing Value Chain Emissions (Section 4.1.5)	Studying and implementing energy efficiency projects (e.g. upgrade of potlines with AP3XLE technology) and low-carbon electricity options at Hillside Aluminium and Mozal Aluminium. Engaging with the South African Government, Eskom and other potential partners to identify options for renewable energy infrastructure to support the decarbonisation of the South African grid. Building partnerships with customers and suppliers, participating in industry groups and product stewardship initiatives, and supporting innovative technology solutions to reduce Scope 3 emissions.	Ongoing as part of South32 group-wide decarbonisation program	Worsley Alumina will report on these value chain studies and initiatives, and potential impact on Worsley Alumina's Scope 3 emissions as part of Worsley Alumina's Annual Environmental Report, and as part of the five-yearly review of the GHGMP. Scope 3 emissions are calculated in accordance with the methodologies in the GHG Protocol Technical Guidance for Calculating Scope 3 Emissions (World Resources Institute, 2013).