The role of Green Alumina in Green Aluminium

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Abstract

Environmental stewardship is central to RUSAL's manufacture of green aluminium. Approximately 80% of RUSAL's aluminium is produced using environmental-friendly hydropower, generated without any harmful emissions. Green alumina also has a key role to play in creating green aluminium. This paper is a comprehensive review of the production of green alumina at Aughinish and the environmental sustainability of the refinery. This sustainability is multi-faceted and includes bauxite residue disposal management, continuous monitoring to ensure there is no impact on the local environment and the minimisation of CO_2 emissions. The "Carbon Footprint" of Aughinish is among the lowest in the industry and has been accomplished through sustained improvements in energy consumption and the conversion of all thermal and electrical energy generation to Natural Gas. The performance of Aughinish in terms of CO_2 emissions is benchmarked against the industry and in particular against Chinese performance. It will be clearly shown that Aughinish is indeed a world leader in this area and a benchmark against which other refineries can be compared. The paper focuses primarily on Greenhouse Gas emissions. Other areas of environmental sustainability of the refinery such as residue management, water emissions and community relations are also reviewed.

Keywords: Green alumina; carbon footprint; greenhouse gases; environmental sustainability

1. Introduction.

Rusal Aughinish Alumina Limited (AAL) refinery is located on the west coast of Ireland. The plant commenced operation in 1983 with a current production capability of 1.99Mt/yr.

AAL has a structured management approach to the operation of the business in terms of product quality, process control, environment, safety, training and analytical capability. The refinery functions within an accredited Environmental Management system (ISO14001) and Energy Management system (ISO50001).

The refinery operates under an industrial emissions license (IEL) issued and enforced by the Environmental Protection Agency (EPA) of Ireland. The environmental management system is a key tool to ensure compliance with the IEL and to drive continuous improvement of the environmental performance of the plant and to safeguard sustainability.

Environmental stewardship is central to RUSAL's manufacture of green aluminium. Approximately 80% of RUSAL's aluminium is produced using environmental-friendly hydropower, generated without any harmful emissions.

Green alumina has a key role to play in creating green aluminium. The production of green alumina at AAL is key to the environmental sustainability of the refinery. This sustainability is multi-faceted and includes bauxite residue disposal management, continuous monitoring to ensure there is no impact on the local environment and minimisation of CO_2 emissions.

2. Energy Efficiency

The International Aluminium Institute (IAI) data shows AAL to be the 7th most efficient alumina refinery in the world (Figure 1). This is a very significant achievement given that AAL is a high temperature refinery and operates a digestion technology which was originally designed over fifty years ago.

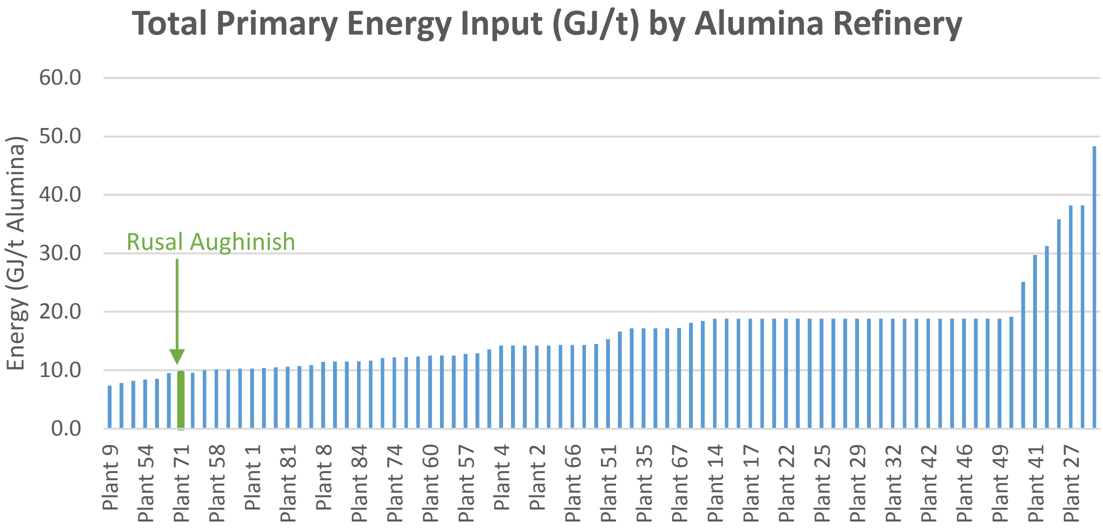

Figure 1. Total energy efficiency by alumina refinery (Source IAI 2015)

The total energy consumption of the AAL (Figure 2) has undergone a continuous reduction over the past 20 years (with the exception of the 2009 global economic crisis). The continuous improvement in energy consumption has been driven through operational improvements, production creep and innovative solutions supporting the economic sustainability of the business.

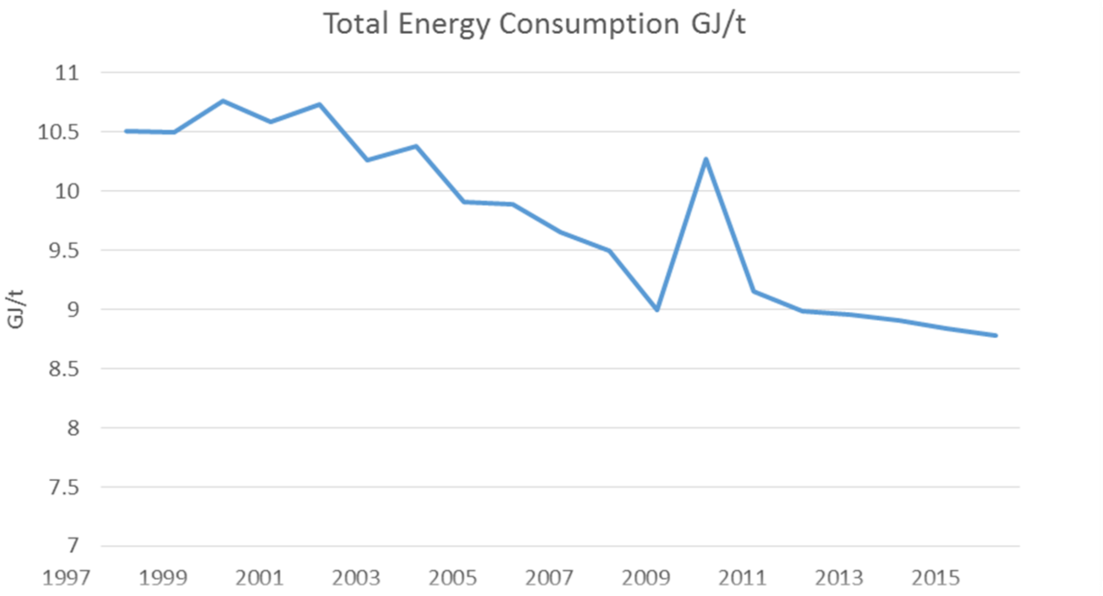

Figure 2. Total energy consumption reduction at the Rusal Aughinish alumina refinery

The recent IAI published data for the Energy Intensity for Metallurgical Alumina refining throughout the world for 2014 is presented in Figure 3.

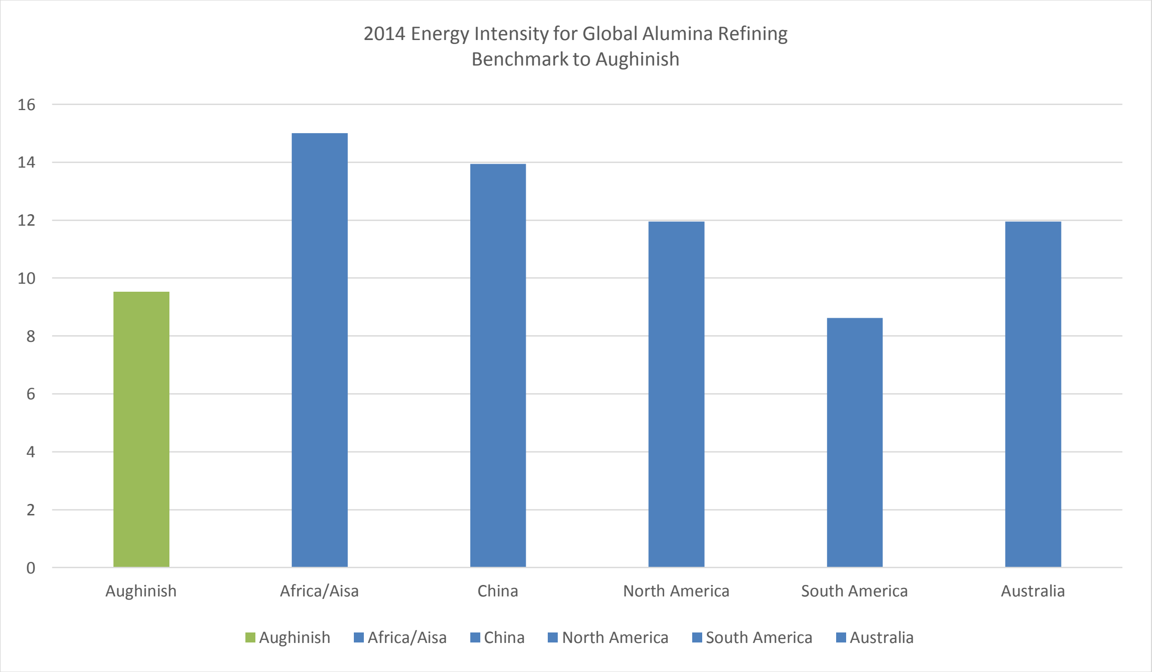

Figure 3. Global Energy Intensity for Alumina Refining - Benchmark with Aughinish

This data also shows that AAL consumes more than 40% less energy per tonne of alumina produced than the average energy consumption for China.

3. Carbon Footprint

The “Carbon Footprint” of AAL is among the lowest in the industry and has been accomplished through sustained improvements in energy consumption and the conversion of all thermal and electrical energy generation to Natural Gas.

3.1 Energy Efficiency

As already stated, refinery energy efficiency is critical in minimising plant air emissions. The average life cycle assessment of Greenhouse Gas (GHG) emissions of the alumina production processes as published by the International Aluminium Institute (IAI) (2015) gives the total GHG emissions for the average alumina plant excluding transport of 3.3 kg CO_2 e/kg Al.

The GHG emission value for AAL is 1.2 kg CO_2 e/kg Al, excluding transport, which is significantly lower than the industry standard. This is as a result of minimising energy consumption, using Natural Gas as the primary energy source and the most modern combustion technology to minimise NO_x emissions.

Alumina production accounts for almost one quarter of the GHG emissions from the aluminium production life cycle on average across the industry. Consequently, improving the sustainability of alumina production has a significant impact on the aluminium industry sustainability as a whole.

3.2 Energy Source

Carbon emissions at AAL have reduced more noticeably in recent years due to the conversion of the all steam and electricity generation along with alumina calcining to gas.

The process of gas conversion began in 2006 with the commissioning of the Combined Heat and Power (CHP) plant which is fuelled exclusively by Natural Gas. In 2010 to 2011, the three calciners were all converted to gas firing from heavy fuel oil and in 2014 two new gas boilers were installed completing the move away from heavy fuel oil to Natural Gas. The trend of total CO_2 emissions is presented in Figure 4 and shows a reduction of 23% in the amount of CO_2 emitted per tonne of production.

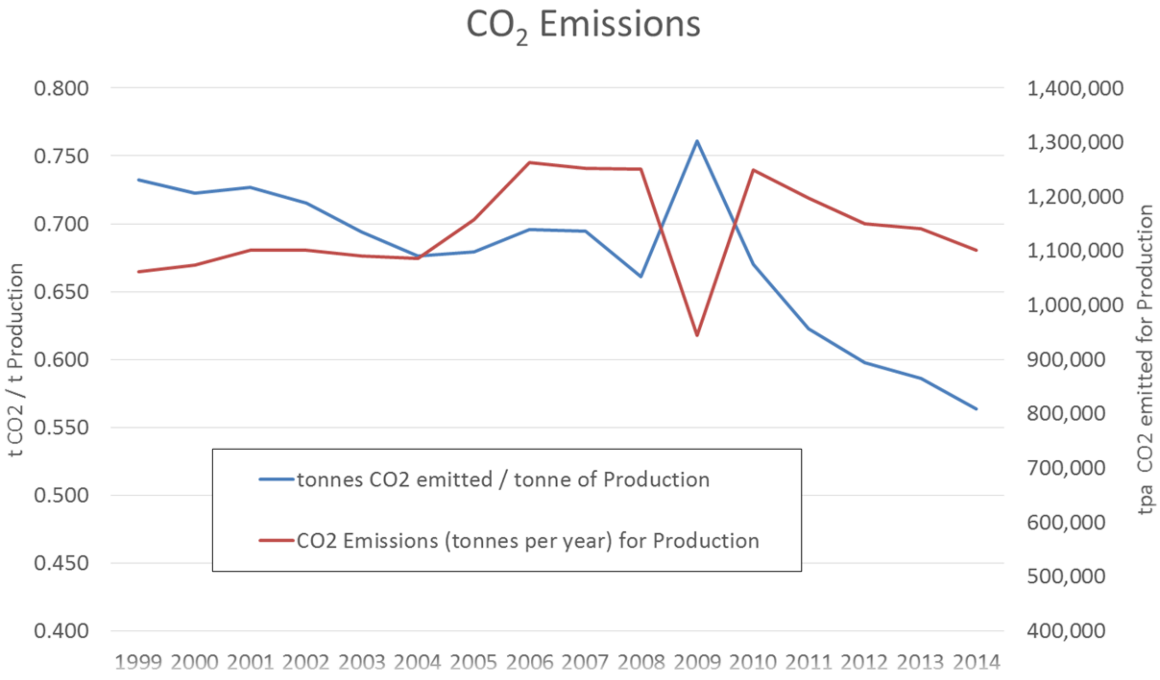

Figure 4. CO2 emissions at Rusal Aughinish Alumina refinery by year

4. Benchmarking CO2 Emissions

The fuel used at an alumina refinery as an energy source along with the refinery's energy efficiency are the factors which determine the amount of carbon dioxide emitted per tonne of alumina produced.

The IAI publishes the fuel mix used in alumina refining by geographic region presented in Figure 5. It shows that 76% of the energy used to produce alumina in China comes from coal. This has a very significant impact on CO_2 as the amount of carbon dioxide per GJ of energy generated by coal is almost 1.8 times greater than from Natural Gas. (Source IEA – 2013)

The fuel mix by geographic region is also interesting and shows a significant move to Natural Gas as an energy source in Europe, North America and Australia whereas South America tend to use little Natural Gas and the majority of its energy still comes from fuel oil. Energy generation for alumina production in Asia and China is still dominated by coal.

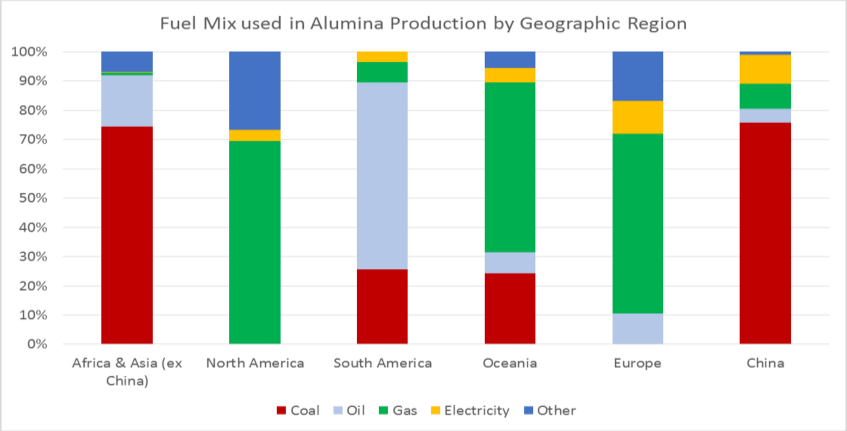

Figure 5. Fuel Mix used in production of Alumina by Geographic region - 2014

A direct comparison can be made between AAL and Chinese production in terms of carbon emissions. Firstly, AAL is 40% more energy efficient than the average Chinese production. Secondly, because AAL produces all its energy from Natural Gas its carbon footprint is very significantly smaller than that of the Chinese production from coal. AAL is producing only 43% of the CO_2 per tonne of alumina when compared to the average Chinese refinery.

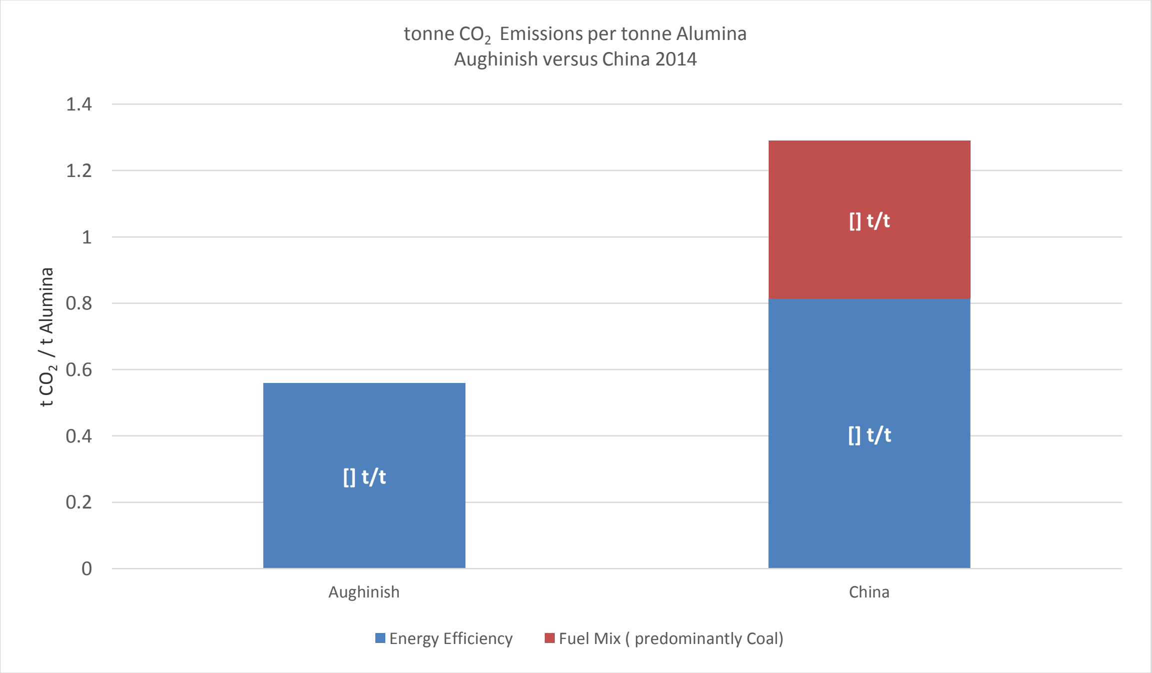

Figure 6. Comparison between Aughinish and Chinese CO2 Emissions per tonne of Alumina

5. Other Greenhouse Emissions

Environmental legislation has become much more stringent as regards air emissions over the past 15 years. In 2003, EU Sulphur Directive resulted in the move away from 3½ % to 1% Sulphur Oil. In 2008 EU Large Combustion Directive (2001/80/EC) placed tighter limits on SOx (1700mg/Nm3) and NOx (450mg/Nm3). Since 2008, AAL in conjunction with Irish Government has been operating National Emissions Reduction Plan (NERP), a transitional arrangement plan to comply with Large Combustion Plant Directive targets. In 2015, new Legislation, the EU Industrial Emissions Directive (IED) further reduced emission limits of SOx and NOx to 200 and 150mg/Nm3 respectively.

AAL responded to these challenges over the same period. SO_x emissions have almost been completely eliminated by the conversion of the plant from heavy fuel oil to a 100% Natural Gas fired plant. A programme to reduce NOx emissions started in 2004 through modification of boiler burner design and avoiding the preheating of combustion air supplied to the boilers. In 2014 AAL commissioned two new Gas fired boilers designed to produce low NOx emissions.

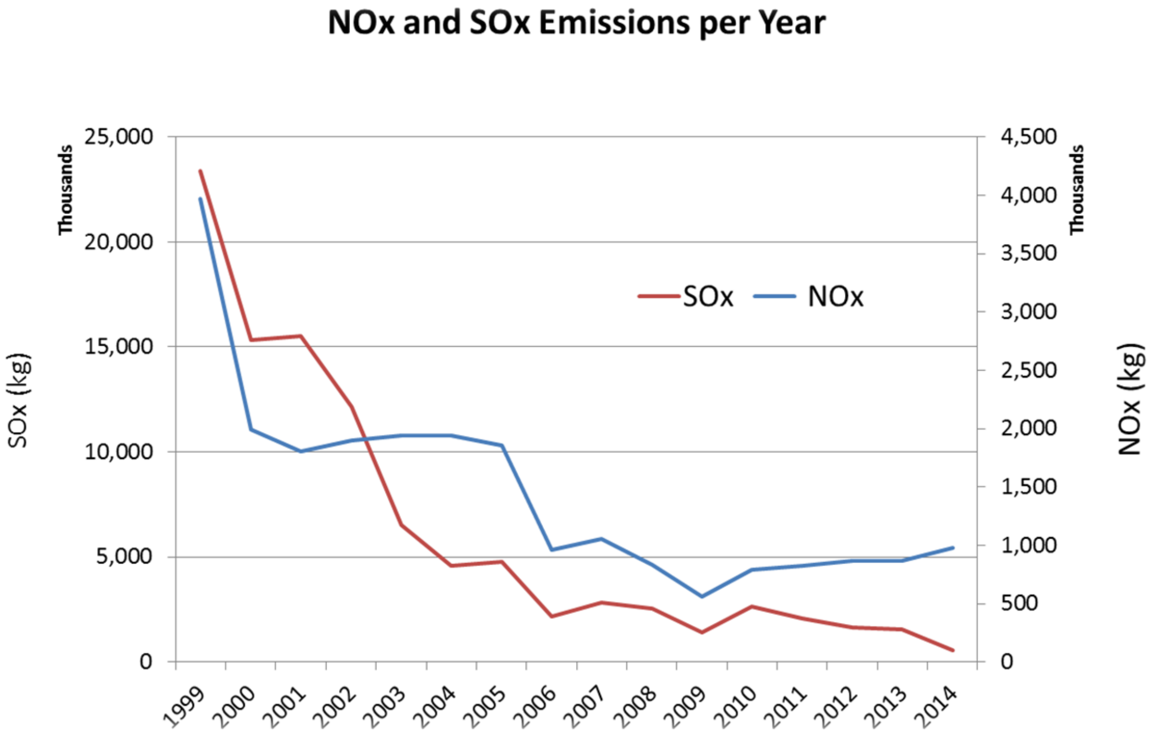

Figure 7. NOX and SOX emissions at Rusal Aughinish Alumina refinery by year

6. Ambient Air Quality

Under the IEL, AAL has 15 licensed Industrial air emission points in refinery:-

Calciners, Boilers, CHP, Crusher building, Transfer Towers, Alumina Loader, Silos

There are also continuous emissions monitoring systems (CEMS) installed at the 10 most critical emission points operating

In addition, quarterly, biannual and annual manual monitoring is carried out with quarterly and annual monitoring reports submitted to the EPA. 2015 emissions to air were 100% compliant and were significantly below licensed emission limit values.

The EPA monitor air quality in Ireland through their ambient air monitoring programme – areas zoned as urban or rural and ambient limits for zoned areas set by EU (CAFÉ Directive). Monitoring results confirm no impact from AAL.

Additionally, AAL monitors ambient air quality at 13 locations for SO_2 and particulates. Monitoring results confirm AAL has no impact off-site.

7. Emissions to Water

The plant and bauxite residue disposal area (BRDA) have been designed and are operated to ensure that run-off from the facility is collected and treated before discharge. The Water Management System provides for collection and treatment of surface water run-off and leachate from the BRDA. AAL has two licensed discharges of treated effluent to the Shannon Estuary namely Industrial/Process effluent and Sanitary effluent

Both discharges are monitored for flow and pH on a continuous basis and for other parameters at weekly, quarterly and six monthly intervals (e.g. suspended solids & BOD). The effluent discharge limits are as follows:

Table 1: Effluent discharge limits as determined by the IEL unless stated as internal

License Parameter	Limit
Discharge pH	6.0 – 9.0 (IEL); 6.5 – 8.5 (internal)
Discharge solids	50 mg/l (max)
Discharge temperature	60 degrees C
Discharge BOD	2360 kg/day

Effluent discharge is 100% compliant to all IEL conditions. Where process conditions allow, treated industrial effluent is recycled back to the plant and is reused in place of raw water.

8. Groundwater

Groundwater quality around the refinery is regularly sampled and analysed.

A Groundwater Risk Screening and Technical Assessment was completed by Golder Associates in 2015 as required by EPA. The major findings are summarised in Table 2 below

Table 2: Effluent discharge limits as determined by the IEL unless stated as internal

Golder Recommended Compliance Points	Golder Recommended Compliance Values	Finding	Action Required
BRDA Observation Wells (OW's) 1- 45	pH <9.5 Cond <1,875 µS Al <0.15 mg/l	**Over 90% wells and springs monitored have a pH less than 9.5. Any exceeding 9.5 are collected and returned to the refinery circuit.**	
Plant Estuarine Springs (ES's) 1-16	pH <9.5 Cond <1,875 µS Al <0.15 mg/l		

All 34 of the observation wells located at the perimeter of the Bauxite Residue Disposal Area (BRDA) are compliant as are 12 of the 16 estuarine springs. The 4 estuarine springs with pH levels greater than 9.0 are all intercepted and recovered back to the plant. Work is in progress to identify and eliminate the need to intercept these 4 springs. AAL also operates an integrity testing for all tank bottoms, drains and bunds with suitable repair programmes. The integrity of all bund structures and tanks is tested and confirmed on an on-going three-year cycle and reported separately to the EPA.

9. Bauxite Residue Management

9.1 Storage Area Design

The bauxite and other process residues generated from the Bayer process are deposited in an engineered facility called the BRDA that has been designed to ensure the long-term stability of these residues. The BRDA is formed by construction of perimeter embankments, an inner and outer embankment with a perimeter intercept channel in between. The bauxite residue is retained by a perimeter stack wall constructed of rock fill, which is raised consecutively in 2m vertical stages. There is also a flood tidal defence berm between the BRDA and the Shannon Estuary foreshore that protects the BRDA from wave and tidal erosion. The BRDA is constructed with engineered composite liners on the underlying strata. All perimeter intercept channels are lined with this engineered composite liner. The BRDA has been designed and operated to ensure that water run-off from the facility is collected and treated before discharge, and that any subsurface seepage from beneath the facility is prevented. The water management system collects and treats surface water runoff and leachate from the BRDA.

9.2 Bauxite Residue Disposal Area Operation

The operation of the BRDA is one of the key enablers in the sustainability of AAL. The deposition method employed is dry stacking of washed, filtered mud which is pumped by positive displacement pumps to the BRDA at 58% solids, where the mud is stacked at a slope of approximately 2.5%, then subsequently farmed to increase the percent solids to 70-75%. The combined BRDA area is effectively a large mono-cell and is divided into 46 operational areas or cells to facilitate short deposition times and thin layer deposition. Partial neutralisation of the mud by atmospheric carbonation through mud farming produces a mud with pH<11.5 which is non-hazardous and is suitable for remediation and revegetation.

9.3 CO2 Sequestration in Bauxite Residue

AAL uses Carbon capture to neutralise its bauxite residues as required by the IEL. An estimated 98kg CO_2 is sequestered per tonne of bauxite residue. This carbon capture is equivalent to 137,200t of CO_2 per year or 12.5% of the total CO_2 emitted by the refinery for alumina production.

Figure 8. Red mud farming and atmospheric carbonation process at AAL

9.4 Post Deposition Treatment

As shown in Figure 8 there are several stages to post deposition treatment. After vacuum filtration the mud is diluted with water, sheared, thinned in an agitated tank and then pumped as a 58% solids paste to the BRDA. In this state the deposited mud cannot yet be traversed by conventional machinery and first must be dewatered and compacted. An amphibious vehicle called an Amphirol is employed to carry out this de-watering and compaction.

The Amphirol travels using scrolls which act as semi-flotation devices to allow the vehicle to move through the residue. As the Amphirol travels it compresses the mud and creates tracks or furrows. These furrows allow the water which has been "squeezed" from the mud to drain along the sloping stack towards the perimeter wall of the cell and into the perimeter channel. Amphiroling for compaction can require up to 20 passes.

Once the mud has compacted to >70% solids by multiple passes of the amphirol, the mud surface is then graded by a bulldozer to level the surface and generate a constant gradient from the discharge (high point) to the perimeter wall (low point). This makes the mud suitable for conventional agricultural machinery to travel and operate on its surface. Also to be capable of being broken into small lumps to allow for exposure to CO_2 in the air. The grading also establishes the base for the subsequent mud layer to be deposited.

Once the mud surface has been re-graded the compacted mud layer must be "ripped" to open the 'compacted mud' and allow it to be easily worked by the other machinery used in the carbonation process. A tractor subsoiler attachment is used to rip and break the compacted mud layer into large lumps. The subsoiler has a working depth of 40-45cm.

The 'ripped' mud lumps must then be broken into smaller lumps and aerated a number of times to carbonate and neutralise the residual caustic. This is achieved by an efficient harrowing unit called a 'spader'. Once the sub-soiler has loosened the mud layer, a tractor-driven spader digs into and harrows the broken up mud lumps. Approximately 10-16 passes of the spader at up to 2 passes per day bring about sufficient exposure and carbonation to reduce the causticity below 30% and to reduce the mud pH below 11.5. The harrowing process using a spader can normally be conducted in a period of 1-2 weeks.

While a mud layer is being harrowed, a lot of voidage is created within the active layer. This is the mechanism by which the mud is exposed to atmospheric CO_2. Once carbonation is completed as evidenced by pH measurements of samples from the cell, the area is then re-graded using a bulldozer to remove any depressions.

Finally, the cell is re-compacted using a vibrating plate compactor or a vibratory roller to maximise in-situ compaction and prepare the cell for the subsequent layer of mud. Through amphirolling, harrowing and final re-compaction, the initial 40 cm deep layer of mud is compacted into a 30 cm deep well-compacted and partially neutralised mud layer. The cell is then ready for the subsequent layer of mud.

9.5 Control of Fugitive Dust

The surfaces of deposited bauxite residue are susceptible to dust blow if not managed properly, particularly when the weather is windy and dry. The potential for dusting is monitored using predictive climatic models.

A distributed control system (DCS) controlled sprinkling system is installed at AAL to control fugitive dust. Clean neutral process effluent is sprayed over the area at a rate of up to 650m3/hr. The entire area of the BRDA is serviced by a bank of sprinklers arranged in 20 separate sprinkler rows. Each sprinkler gun rotates 360 degrees providing 50 m^3/hr irrigating an area of approximately 50m^2. Farming of top layer reduces potential for dusting.

The long-term suppression of fugitive dust will be achieved by installing a vegetation cover with sufficient density to retain the residue material.

9.6 Geotechnical Stability

All phases of the BRDA have been designed and constructed appropriately to ensure that it is structurally stable under operational and expected closure conditions. Quarterly monitoring is undertaken by Golder Associates for AAL.

Monitoring of the inclinometers, extensometers and piezometers combined with cone penetration tests (CPT) confirm that the BRDA walls are stable at the current elevations and that the BRDA structural integrity is in accordance with the design.

Red mud farming improves the stability of the BRDA by increasing the deposit density and results in life extension of the BRDA.

9.7 Deposit Closure Plan

The establishment of a sustaining vegetation cover is the preferred method for post-closure management of residue storage area to control erosion and dusting of the residue and improve its aesthetic impact. Effective BRDA mud farming is the key enabler to achieve this.

Establishment of vegetation on the bauxite residue stored at the BRDA has been successfully demonstrated by greenhouse and field trial studies undertaken by AAL and University of Limerick. To achieve this, amendment of the residue is required and an understanding of the basic physical and chemical principles for reclaiming alkaline residues has been established.

Figure 9. Steps in the rehabilitation and revegetation of deposited red mud

The underlying principles of amending the residue are:

- Creation of drainage channels to assist in drying of *the residue*
- Partial neutralisation of the bauxite residue to reduce pH
- Application of process sand to improve texture and structure of the residue substrate
- Amendment with gypsum ($CaSO_4$) to replace entrained sodium with calcium
- Addition of nutrients (compost)
- Seeding with native grass and cultivar species.

Field trials have demonstrated that re-vegetation can be achieved through a process of physical and chemical amendment of the red mud. A number of treatments were implemented to investigate performance levels of vegetation growing directly on the surface of the residue. Optimum performance was produced by physically amending the substrate with process sand and gypsum.

Previously revegetated residue areas were surveyed after 6 and 8 years. Species diversity was recorded and compared to the initial seed mixture of 6 species. The survey showed significant increase in biodiversity and that there were 50 species belonging to 40 genera and 16 families and indicates that colonisation by further species occurs on areas once vegetation is established.

Figure 10. Evidence of thriving ecosystem on revegetated red mud

9.8 Wetlands Project

A novel approach to ensure that BRDA leachate can be passively treated and made suitable for discharge after 5 years of BRDA closure is to incorporate constructed wetlands into the Closure Plan. Constructed wetlands are gaining global acceptance by regulators in mine closure for acidic leachate. However, little research had been conducted into the using wetlands to treat alkaline bauxite residue leachate.

In 2012, AAL received funding from both Rusal and the International Aluminium Association (World Aluminium) for a four-year study led by Dr. R. Courtney of the University of Limerick investigating the use of a constructed wetland to treat residue leachate.

The field trial has been very successful and the results have shown that leachate can be successfully treated to achieve pH <9.0, and a wetlands system can be incorporated into the final closure plan of the BRDA at AAL, to ensure ongoing compliance.

9.9 Final Land Use

The long-term sustainable land-use of the BRDA surface will be restricted to those activities that do not increase the pollution potential of the rehabilitated facility. In deciding the most suitable end use for the BRDA, it has been determined that activities which may lead to over-grazing, poaching, cultivation, uprooting of trees by wind-blow and other surface disturbance will be avoided. The preferred land-use option, based on current knowledge of the chemistry and biology of the sown grassland cover, is to develop the area for nature conservation.

AAL operates in a rural, agricultural area bordering areas of special conservation. A section of AAL land to the north of the BRDA has already been developed as a Bird Sanctuary and there are also butterfly and dragonfly sanctuaries on site. Areas to the east of the BRDA are already used as nature trails for walking and jogging. Our relationship with our local community is paramount to having a Social License to Operate. The final development of a nature conservation area is in keeping with AAL’s relationship with its local community.

10. Conclusion

The environmental management of the AAL operation is overseen by the Irish EPA through the Industrial Emissions License (IEL). This is a statutory instrument and by the EPA’s own admission is the strictest licence in Ireland. AAL’s compliance with its IEL is 100% and recognized as exemplary by the EPA.

AAL is one of the most energy efficient plants within the global alumina industry. The “Carbon Footprint” of AAL is among the lowest in the industry and has been accomplished through sustained improvements in energy consumption and the conversion of all thermal and electrical energy generation to Natural Gas.

SOx emissions have been eliminated and NOx emissions have been significantly reduced over the last 15 years.

AAL responsibly stores bauxite residue in a world class BRDA, ensuring that all residue is neutralised to less than pH 11.5 and drives innovation in residue rehabilitation and leachate management.

Other areas such as emissions to air, emissions to water, groundwater plus closure plans are all well managed, continuously improving and with little adverse environmental impact.

Relations with both the regulatory body, the Irish EPA, and the local community are excellent.

Central to this performance and on-going improvement are the two international standards, namely ISO 14001 for Environmental Management and ISO 5001 – Energy Management that AAL operate. AAL is fully accredited to both standards. ISO 5001 is more data driven and focuses on energy performance improvement, while ISO 14001 provides a more qualitative look at all significant environmental impacts of an organization. ISO 14001 guides the organization's environmental programs in a comprehensive, systematic, planned and documented manner.

In conclusion, the overall environmental footprint ensures that AAL produces green alumina with minimal impact on the environment and the community and thereby plays its role in the manufacture of green aluminium in the overall Rusal group.

Finally, the author would like to thank M. Fennell and J. Clohessy from AAL for their assistance in compiling this paper.