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Cleaner Production in Alcoa

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ABSTRACT

Alcoa World Alumina Australia is committed to sustainability principles as a basis of business success into the future. In March 2001, Alcoa Inc chairman Alain Belda announced a set of far-reaching environmental goals for the corporation, with the challenge that they should be achieved in ways that enhance economic and social performance, while substantially reducing environmental impact. Application of Cleaner Production methods is seen as the key to achieving these joint objectives. In Australia Alcoa has launched a co-ordinated effort to accelerate our application of Cleaner Production principles to delivering cost-effective in-process solutions to environmental issues. Our Western Australian Operations are a signatory to the WA Cleaner Production Statement, through which we provide a Cleaner Production Plan to the State Government on a voluntary basis. This paper describes in general terms Alcoa's goals, achievements and directions in applying Cleaner Production to enhance business performance in the economic, environmental and social dimensions. Quantification of the benefits and tracking of progress in quantitative terms is a key challenge for the future

INTRODUCTION

Alcoa World Alumina Australia is a trading name of the public company, Alcoa of Australia Limited, whose principal shareholders are US-based Alcoa Inc (60 per cent) and the major Australian resources company, WMC Limited (39.25 per cent). The company owns and operates alumina refineries at Kwinana, Pinjarra and Wagerup in Western Australia, with a combined capacity of 7.3 million tonnes per year, or about 16 per cent of world demand. The bauxite ore is provided from the Huntly and Willowdale mines. The alumina from the three refineries is shipped to smelters all over the world from Alcoa's two ports in Kwinana and Bunbury. In Victoria, Alcoa owns the Point Henry smelter near Geelong, and is the operator of the Portland smelter in which it has a 55 per cent interest. The combined capacity of these two smelters is 530 000 tonnes per year, with most of the aluminium being exported (Alcoa in Australia Annual Review, 2000).

All of the activities of Alcoa's global business are co-ordinated through a comprehensive system of business management, the Alcoa Business System (ABS). ABS is an integrated set of systems and tools organised to provide a common language and unencumbered transfer of knowledge across businesses and geographies. ABS adapts aspects of the Toyota Production System, Kaisen engineering and Quality Management concepts to the Alcoa business environment. It is built upon sustainability principles and the Triple Bottom Line, and is underpinned by the key principles of *make to use, elimination of waste* and *people as the linchpin*. In the production aspects of the business, the principles of Cleaner Production are a natural fit with ABS, primarily through the Elimination of Waste principle.

Cleaner Production is the continuous application of an integrated preventative environmental strategy to increase eco-efficiency and reduce risks to humans and the environment. It can be applied to processes, products and services. For processes, Cleaner Production includes conserving raw materials and energy, eliminating the use of toxic materials, and reducing the quantity and toxicity of all emissions and wastes (UNEP, 2001). This is done in an environment of continuous improvement, relentlessly driving out waste, striving for excellence and improving economic performance.

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COMMITMENT

At the Alcoa Inc Annual General Meeting in April 2001, Chairman and CEO Alain Belda announced sweeping new environmental goals for the Corporation (Belda, Alcoa Update to Shareholders, 2001). These goals are to be achieved in a manner that improves financial performance as well as environmental performance, and so clearly call for a Cleaner Production approach. Specifically, the goals are to achieve the environmental impact reduction targets set out below.

From a base year of 2000:

- a 60 per cent reduction in SO_2 emissions by 2010;
- a 50 per cent reduction in Volatile Organic Carbon emissions by 2008;
- a 30 per cent reduction in emissions of nitrogen oxides by 2007;
- an 80 per cent reduction in mercury emissions by 2008;
- a 50 per cent reduction in landfilled waste by 2007; and
- a 60 per cent reduction in process water use and discharge by 2008.

From a base year of 1990:

- A 25 per cent reduction in greenhouse gas emissions by 2010. Assuming success with the inert anode technology, a 50 per cent reduction by 2010.

In addition, Alcoa is committed to achieving an operating cost reduction of $US 100 M by 2005 from energy and raw materials savings, environmental management cost reductions and recycling.

These targets were set following a consultation process covering all Business Units in Alcoa, and so while undeniably challenging stretch goals, there is a strong belief within the organisation that they can and will be achieved.

ACHIEVEMENTS TO-DATE

While the journey is at an early stage, significant progress has already been made in a number of areas. Some illustrative examples are given here.

Spent pot lining

A world-first in treating a waste product from the aluminium smelting industry has been developed at Portland Aluminium in Victoria's south-west (Mansfield, Swayn and Harpley, 2002). Spent pot lining (SPL) is a waste product of the electrolytic process in the smelting of aluminium. Prior to treatment SPL is considered to be a hazardous waste in most countries because it contains significant quantities of absorbed fluoride as well as traces of cyanide. Historically, the disposal of SPL has mostly been in landfill because of difficulties in the development of a technically and economically sound treatment process. Increasing concern about SPL landfilling practices is resulting in regulations in some countries to ban this form of disposal. As a consequence, stockpiling of SPL is occurring in an increasing number of sites worldwide pending the development of a successful treatment process.

Finding a solution to this issue has been the subject of an eight-year $26 million research and development program that harnessed technology and expertise developed by Portland Aluminium, Alcoa Inc., Ausmelt Ltd, and CSIRO. The result has been a unique process with worldwide implications for the sustainability of the aluminium industry. It turns a hazardous waste into a high value recycle stream (aluminium fluoride) returning to the smelting process, and an inert material suitable for a number of applications, in particular road and concrete making.

The *Alcoa Portland SPL Process* is an excellent example of the successful application of Cleaner Production and ABS principles, providing a solution that generates valuable by-products and significant cost savings while eliminating waste and solving a major environmental issue. Further details are given in the paper by Mansfield *et al* (Mansfield, Swayn and Harpley, 2002) in this conference.

Uses of bauxite residue

In producing 15 million tonnes of alumina in 2000, Alcoa World Alumina produced 20 million tonnes of bauxite residue worldwide. In concept, this residue is a modified soil, which has been depleted of aluminium minerals and has been contaminated with caustic soda through the alumina refining process. In general it is high in iron and silica minerals, and the clays have been replaced by zeolites. A wide range of uses have been identified for this material, including brick making, an additive to cements and plastics (Glenister, Smirk and Pickersgill, 1992; Prasad and Singh, 1995), and even as a wood substitute in building and as a source of iron and other metals (Hindustan Times, 2001). More sophisticated processes, such as the formation of mineral polymers for fabrication of corrosion resistant pipes, and as a scrubbing medium for gas steams, have also been suggested.

In Western Australia, Alcoa has been working with the Department of Agriculture to develop the mud fraction as an agricultural product, Alkaloam™ (Agriculture WA, 2001). It has proven extremely successful as a soil amendment for nutrient deficient acidic soils, and can increase the productivity of farmland (by up to 24 per cent on clover pastures). It has been extensively trialled in the Peel-Harvey Catchment south of Perth. In these acidic soils, the immediate liming effect of the residual caustic is highly beneficial in increasing soil productivity. It also increases fertiliser efficiency by chemically binding phosphorous. This reduces phosphorous leaching while leaving the phosphorous available to plants, producing economic benefits to the farmer as well as positive benefits to the environment. By greatly reducing phosphorous run-off, Alkaloam has the potential to have a major benefit in helping to address one of Western Australia's most important environmental issues, the eutrophication of waterways as a result of nutrient run-off in the South West of the state.

Another very successful, but at this stage small scale, application of bauxite residue is in the Ecomax™ sewage treatment system. The incorporation of bauxite residue into the design of septic sewage treatment systems produces a highly effective removal system for nutrients, pathogens and heavy metals. The resulting effluent is of unusually high quality (Bowman, 1997). The advantages of the system are cited as:

- very high phosphorus and nitrogen removal,
- high removal of BOD and suspended solids,
- disinfection without chemical addition,
- heavy metal removal,
- gravity driven process,
- very long life,
- negligible maintenance, and
- no moving parts.

This technology offers a very effective, low cost means of safe disposal of sewage on-site. In rural areas and in the expanding semi-rural areas adjacent to our cities, this provides a low cost means of sewage treatment for owners of small holdings. For small communities and industries it has the potential to avoid the creation of costly sewage systems, thus also saving water. Such a concept could also be transferred to suburban situations, reducing the pressure on our increasingly scarce water resources. Despite these advantages, the uptake of this technology has been relatively small. The reasons are primarily political and social rather than technical, and so there remains a significant opportunity in relation to the deployment of this beneficial technology.

Bauxite residue management

The residue produced after extracting the aluminium minerals from bauxite is a slurry containing high levels of caustic soda. The modern Bayer process thickens this slurry and washes it by counter-current decantation. This process recovers valuable caustic soda and provides a lower soda residue for storage, at higher solids content. This standard practice is an excellent example of Cleaner Production in design, addressing as it does both the economic and environmental aspects of the Triple Bottom Line. Nevertheless, this still results in a 'wet lake' storage process, which has a number of disadvantages. These include high area requirement, high exposed liquid area resulting in aerial carbonation and hazards to wildlife, and potential for leakage.

In the 1980s Alcoa developed a 'dry stacking' technology, which overcame most of these disadvantages. A final stage of thickening and washing was installed using Eimco high-density thickeners ('Superthickeners'). This process results in a material that contains greater than 50 per cent solids. Soda recovery is substantially improved, and the resulting mud has excellent rheological properties, which allow it to stack and dry as a solid and dramatically reduce the open wet area. With the addition of an under-drainage system, the infiltration of rainwater continuously washes soda out of the residue stack and recovers soda to the refinery, at the same time reducing the sodicity of the deposit (Marunczyn and Laros, 1992). Composite clay and synthetic liners complete the picture of a relatively benign residue, isolated from the surrounding environment, and taking up the minimum of area. The material stored in this way is much more readily available for downstream beneficial uses than was possible with wet disposal methods (Glenister, Smirk and Pickersgill, 1992).

This method of storage represents current best practice in Alcoa, and is considered as a benchmark process both by the State government and other industries. Research efforts directed at continuously improving these methods are ongoing.

Industrial ecology – sodium oxalate as a product

Sodium oxalate is produced in the Bayer process from the degradation of organic contaminants in the caustic liquor. To preserve process and cost efficiency, it is necessary to remove oxalate from the liquor, and recover the soda to the process. The soda recovery is normally achieved by roasting the oxalate to carbonate in a kiln. The carbonate is then reacted with lime to recover the caustic. In 1999, Alcoa formed a partnership with Vanadium Australia PL (VAPL) for the supply of sodium oxalate to their process. This synergistic arrangement allowed VAPL access to a low cost source of soda, while allowing Alcoa to recover the residual value of the soda without the need for additional processing. The arrangement was one of the key enablers to the establishment of this new industry in Australia. The site is at Windimurra, near Mt Magnet in Western Australia. The plant was commissioned in late-1999 at a cost of $A 120 M, and is potentially the world's largest producer of primary vanadium (PMA, 1999).

General waste reduction

All of Alcoa's operating locations are committed to continuous reduction in waste generation to landfill. This is driven by the Alcoa Business System, which has 'relentless pursuit of waste reduction' as one of its basic tenets, and by the corporate environmental vision of major reductions in waste production (Belda, 2001).

In Victoria, Alcoa was the first major industry to be awarded EcoRecycle Victoria Waste Wise accreditation, and in 2001 achieved reaccreditation as part of the ongoing audited continuous improvement process run under the Victorian Government's Waste Wise program. The program has prompted a number of changes in the way of doing business, and has resulted in some remarkable outcomes in waste reduction, achieving an overall reduction in waste to landfill of 98.8 per cent. This has been accompanied by a reduction in waste disposal costs of $1.5 M per annum. These achievements have earned Alcoa's Victorian Operations an Alcoa Worldwide Environmental Excellence Award, and have enhanced the community's understanding and acceptance of the company. A key aspect has been the establishment of Materials Recovery Facilities at the Pt Henry, Portland and Anglesea sites. These centres control the types and quantities of materials that leave the site, and facilitate sorting for recycling, thus dramatically reducing the amounts of materials sent to landfill. Following major reductions in volumes to landfill, emphasis is now on Cleaner Production principles to provide ongoing improvements by integrating operational performance and process improvements to minimise waste production (EcoRecycle Victoria, 2000).

In Western Australia, Alcoa's Pinjarra Refinery was awarded the Recycling and Waste Reduction Award in 1995 by the State Government Department of Environmental Protection, for reducing waste to landfill by 82 per cent. Some examples of the waste minimisation programs that were introduced include:

- A combined composting and worm farming process, which completely eliminated putrescible wastes to landfill. This program also created worm castings for the refinery gardens, which significantly reduced fertiliser costs.
- Developing a waste management contract with Cleanaway, focusing on sorting at source to maximise recycling.
- Implementing the three bin system into all canteen and crib room areas to sort recyclables from waste materials.
- Replacing every office bin with a Recyclables Only bin.
- Establishing an integrated Recycling Centre and Material Recovery Facility. The centre has a computerised gate entry system that collects data on what materials are being disposed of or recycled. The data is analysed on a monthly basis to define the major waste streams from which the waste management team develops and implements Cleaner Production initiatives.
- Working with suppliers to jointly progress Cleaner Production programs to reduce costs and wastes for both parties.

All of Alcoa's Western Australian plants have now adopted the main elements of this process, and have established a common goal of 'zero non-process waste to landfill by 2008'.

Process spills reduction

Efficient heat exchange is one of the key energy efficiency aspects of all modern alumina refineries. The Alcoa plants rely heavily on shell and tube heat exchangers for heating and cooling liquor streams. Hot Bayer liquors result in scale growth on the heat exchange surfaces, necessitating regular draining for descale. The design of the heaters typically has required the hot liquor to be drained to a concrete pad and recovered to the main liquor stream via sumps. This procedure involves potential losses of liquor, and environmental and safety risks. By redesigning the piping systems, it is now possible to use water as a flushing medium and eliminate the need to drain liquor to the sumps. The new design is being implemented on new installations, and is being progressively retrofitted to existing installations. This is an example of the Cleaner Production by technology modification.

Use of waste oils in dust suppression

Dust suppression is required at Alcoa's bauxite residue areas in order to meet community and regulatory requirements for dust emission levels. A system of sprinklers is used on the open drying areas to control dust. Operators utilise a dusting prediction system based on weather and atmospheric conditions to control the sprinkler system. Other dust sources, including access roads, dykes and sand piles are not covered by the sprinklers, and have in the past been managed by water carts and dust suppressant chemicals. Alcoa's operations produce significant quantities of waste oil, primarily from large earth moving equipment. Extensive research and evaluation has found that these waste oils can be very effective as dust suppressants, and can be used without any detrimental effects on the environment.

For use as a dust suppressant, the used oil is first emulsified and then sprayed on the dyke walls, sand hills and roads within the residue area. The oil is superior to most other suppressants on roads. Most dust suppressant materials work by producing a hard compacted surface, which tends to be broken up by vehicle traffic. In contrast, the oil coats the individual sand grains, so that when vehicles travel over the surface the sand particles can move around without compromising dust control performance. Strict controls are maintained on the impurities in the oil, and only oils that meet stringent standards are used. The controlled use of oil in this application had been approved by the Department of Environmental Protection. It has been demonstrated that due to natural bioremediation processes the total petroleum hydrocarbons concentration is at undetectable levels two meters below the oil treated surface. As an added environmental protection measure, oils are only used for dust suppression within the sealed areas of the bauxite residue deposits. In this example of Cleaner Production, an environmental benefit (dust suppression) is obtained by internal reuse of a waste product (used lubrication oils), which substitutes previously purchased chemicals (dust suppressant) and reduces overall operating costs.

Portland Aluminium's cleaner production program

In 1990, Portland Aluminium began a comprehensive Cleaner Production initiative (James, 2001). Their initial goals, which would have seemed ambitious in the extreme at the time, focused on achieving zero waste to landfill, including both process and general wastes as separate aspects of the overall program. In addition to the breakthrough in spent pot lining disposal and general waste disposal outlined above, Portland's program was extended to all aspects of the operation, from raw materials delivery to casting operations.

In the raw materials area, alumina and carbon are transported 4.2 km by conveyor from the port to the smelter. In the original system, spillages occurred to the extent that significant cleanup and disposal to landfill were required to avoid cross contamination. The installation of additional covers and a ducted vacuum system has eliminated spills and enabled recovery of dust to the production process. In addition, significant reductions in noise and in maintenance costs have been achieved. Substitution of liquid pitch for pencil pitch in carbon anode manufacture has simplified handling and improved operational efficiency and environmental performance.

In the electrode manufacture operation, maintenance processes have been modified to facilitate full recycling and reuse of all carbon materials. Maintenance that was previously done *in situ* is now carried out off-site, involving prefabrication of large sections of furnaces and minimising the need for personnel to enter the hot baking furnace.

There have also been numerous cleaner production improvements in the smelting operation. A focus has been in the cell maintenance and rebuild area, where the electrolytic cells are cleaned out and relined, and newly lined cells are cured by gas firing. A specially designed facility has been introduced to reduce the dust and noise emissions from this process, and specialised equipment has been designed to facilitate the recovery of aluminium for reprocessing, and other materials for reuse. Fume extraction systems collect and scrub volatile organic compounds from the gas stream before release.

The safety and process efficiency of the casting area has been improved by the introduction of robotics for skimming ingots during casting. The skimming process is essential for good surface quality, and reduces the risk of moisture entrainment that can lead to explosions during remelting. The use of robotics reduces the risk of exposure of personnel to splashes and fumes.

The overall benefits of these improvements are many. From reductions in raw materials losses alone the increase in annual revenues is over $A 1 M per annum. In addition the working environment has been improved. Substantial improvements in energy use and process efficiency have been achieved, resulting in both economic savings and reductions in environmental impact, including greenhouse gas emissions reductions.

Similar improvement processes are in place at the Pt Henry smelter, with corresponding environmental, social and economic benefits.

WORK IN PROGRESS

Emissions reduction – Wagerup refinery

Alcoa's Wagerup refinery has set itself the task of becoming a world benchmark in refining excellence in relation to emissions to atmosphere within a short time frame. As one of the most modern refineries in the Alcoa system, the refinery starts from a favourable base line. The Wagerup initiative is in part a response to the Corporate environmental challenge, and partly in response to local community expectations.

Emissions to atmosphere first became an issue with the commissioning of the Liquor Burner for organics removal in 1996. The additional and unfamiliar odour from the Liquor Burner stack in the rural setting of Wagerup elicited concern from the local community. In response to this, a Catalytic Thermal Oxidiser (CTO) was added to the equipment. This reduced the level of Volatile Organic Carbon (VOC) emissions by 90 per cent. The measured odour reduction was somewhat less, in the order of 80 per cent. Further research led to the installation of a dehumidifier in 2002, which is expected to provide a further odour reduction of at least 50 per cent.

A comprehensive survey of odour sources at Wagerup (Coffey, in prep) indicated a number of other odour sources which needed to be addressed to reduce the overall refinery odour emissions. The calciner stacks were identified as a significant point source. The response to this has been a combination of in-circuit Cleaner Production initiatives and end of pipe treatment. Reductions in the fixed and washable soda levels in the feed to the calciners has resulted in significant reductions in odour generation. This has been achieved at minimal cost by a combination of changes in alumina tri-hydrate precipitation conditions, a change in the dewatering aid used on the filters, and a change in the source of the condensate used to wash the filters. In addition, a multi-flued stack configuration is to be installed to improve the dispersion of the exhaust gases, which is expected to reduce the odour levels at the refinery boundary by at least a further 50 per cent.

Research has also identified condensates as significant sources of odour at the refinery. A reconfiguration of the condensate system to take advantage of photochemical, oxygen and biological effects in the cooling pond is currently under trial. Results to-date indicate that this will result in a significant reduction in overall refinery odour emissions at minimal cost. One of the issues identified is a small penalty in energy, and energy recovery will be a focus of future improvement activities.

A major project is under way to reduce emissions in the 'hot' areas of the plant, by capturing vapours that are currently emitted to air, and routing them to the powerhouse for the organic components to be burnt. The vapours from the digestion, evaporation, heat interchange and causticization areas will be collected and manifolded. The overall reduction in odour emissions will be around 15 per cent. Improvements in energy recovery will provide some degree of offset to the cost.

NO_x emissions at Wagerup are well within all regulatory requirements. However NO_x has been identified as a contributor to refinery odour, and there is a corporate goal for NO_x reduction worldwide. It has therefore been decided to address NO_x reduction at Wagerup. In the first half of 2002, low NO_x burners will be retrofitted to two boilers and the gas turbine, resulting in a reduction in NO_x emissions of 40 per cent.

By the end of 2002, capital in the order of $A 27 M will have been expended on emissions reduction equipment, starting with the CTO in 1999. These capital costs, along with additional operating costs in the order of $A 1 MPa, are indicative of the cost of end of pipe treatment and of Alcoa's commitment to emissions reduction. In addition, the Cleaner Production focus is resulting in significant additional emissions reductions at minimal cost.

By the end of 2002 overall odour emissions will have reduced by 61 per cent since the start of the program in 1999, on an absolute basis. Over the same period refinery output will have increased 22 per cent, giving a reduction in refinery odour emissions intensity of 67 per cent.

Energy efficiency improvements

The extraction of aluminium from its ores and smelting to metal are inherently energy intensive processes, because of the chemical nature of aluminium itself. The efficient use of energy therefore is of primary concern in design, operation and improvement at all levels.

Significant improvements in energy efficiency have been achieved in Alcoa's operations in the decade to 2000. In refining, the greatest improvement has been at the Kwinana refinery, where a 13 per cent improvement in energy efficiency has been achieved. This has been done through production increases driven by plant yield and operating efficiency improvements, as well as specific energy efficiency improvement projects. Of the three WA refineries, Kwinana remains the one with the largest opportunity for energy efficiency improvement. Accordingly, a 'Big Energy Project' is being planned for Kwinana under the Commonwealth Energy Efficiency Best Practice (EEBP) program (EEBP web site, 2002). This project is a co-operative project between Alcoa and EEBP, which seeks to identify and progress significant energy improvement opportunities in the plant. The process revolves around a 'Creativity Workshop', in which opportunities for improvement are identified. This is followed by a risk-based assessment of priorities, and compilation of a final list of projects to be progressed. Because of the likely capital intensity of some of the projects, it is expected that the overall project will extend over several years. At the same time, a training program in the efficient use of energy will be introduced to address day-to-day operational opportunities. In addition, a capital works program is being prepared for the refinery operations to meet the 2010 challenge of a ten per cent reduction in energy intensity.

In Victorian Operations, the Anglesea Power Station achieved significant improvements in turbine efficiency following maintenance and upgrade work in 1999. This brought the station's greenhouse intensity to 1.27 tCO_2/MW-h, compared to 1.34 tCO_2/MW-h, which is the average Victorian power generation used by the Greenhouse Challenge program (Alcoa in Australia Annual Review, 1999).

In 2002, Portland Aluminium continues a major project to improve power distribution in the smelter's reduction cells through a bus bar retrofit. This is expected to provide savings of 2.8 per cent in energy efficiency and greenhouse intensity. Alcoa is also working closely with the Sustainable Energy Authority of Victoria to progress a range of energy improvement opportunities, mainly focusing on behavioural issues.

Greenhouse gas reduction

In the period from 1990 to 1999, Alcoa's smelting operations have made a step change improvement of 90 per cent in the production of on-site greenhouse gas emissions (Australian Greenhouse Challenge, 2002). This has been achieved primarily by reductions in the generation of perfluorocarbons (PFCs) that result from unstable pot operation and the occurrence of 'anode effects'. Improved operating strategies and steadier operation has led to reduced cost of production as well as a dramatic lowering in the frequency and duration of anode effects, and a corresponding reduction in the production of PFCs.

PFCs are powerful greenhouse gases, having a CO_2 equivalent of greater than 6000 gCO_2e/gPFC (Greenhouse Challenge Workbook, 1997), and a lifetime in the order of 10 000 years, 50 times that of CO_2 (Australian Greenhouse Office, 1997). Reduction in PFC emissions is therefore a very effective way of reducing overall greenhouse emissions, and is a good example of the application of Cleaner Production principles to benefit synergistically the environment and the cost of production.

A program to further improve pot performance by reducing the amount of superfine alumina in the product delivered to the smelters has been initiated in 2002. This project aims to find ways to improve alumina quality that are cost positive for the refineries, and which will have a number of beneficial effects for the smelting customers, one of which will be reduced greenhouse emissions.

The solid residue from alumina refining is what remains of the bauxite after the alumina has been extracted. The process liquor associated with the residue is strongly alkaline (pH 14). Treatment of residue with CO_2 to neutralise the caustic content is currently being trialled at Alcoa's Kwinana refinery. The technique has multiple benefits, as it provides a CO_2 sink, reduces the alkalinity of the residue for storage, and potentially opens up a broader range of uses for the residue as a by-product.

Green engineering

'Green Engineering' seeks to incorporate environmental and social aspects into engineering thinking, and to encourage 'whole of process' thinking, which includes both internal process interactions and overall life cycle aspects of components and systems, into engineering design (Allen and Shonnard, 2001).

In an effort to facilitate the move towards 'whole of process' thinking in the design of new processes and plant, Alcoa has introduced a formal Cleaner Production Review into the development phase of all major capital projects. The object of the Cleaner Production Review is to ensure that the project design is thought of in the broader environmental and social context, rather than just as an isolated project for economic efficiency alone. In this way cleaner production solutions can be designed into plant from the outset, avoiding the need for expensive end of pipe retrofits in the future. The engineering team is also encouraged to think in terms of whole of system engineering and the full life cycle of the plant.

The Cleaner Production review is conducted in the early stages of project planning. The first step is to produce an input/output diagram for all significant raw materials and emission types, and to review this with the project team in the context of specific environmental and social goals. Baseline performance is established for each major aspect. Opportunities for improvement are identified through a workshop process, and then prioritised using a risk-based methodology. The final list of opportunities to be included in the project is then made following economic analysis. This enables environmental improvement goals to be defined for the project. A tracking system is then used to evaluate the performance of the completed project against those goals. At present this system is in its formative stages, so it is not possible to quantify the benefits as yet. To do so will be a key objective of the tracking system.

Industrial ecology

Alcoa's Kwinana alumina refinery is a lead industry within the Kwinana Industrial Area (KIA), 35 km south of Fremantle in Western Australia. The KIA incorporates a wide variety of large and small industries, compactly co-located on the shores of Cockburn Sound. A variety of synergistic relationships have grown up in the area over its 50-year history, as small industries have become established to meet the needs of the larger industries, and as opportunities for use of wastes and sharing of resources have been identified. In 1991 the Kwinana Industries Council (KIC) was established to work for the long-term viability of the industrial region. Its goals include co-ordinating a range of inter-industry activities, including air and water quality monitoring and management and emergency response management and co-operation. It also seeks to promote a positive image of the KIA with the community, local and state governments and regulatory bodies, and to highlight the major contribution that the area makes to the economic and social wellbeing of the State (KIC web site).

In 2001 the KIA was identified by the Sustainable Resource Processing Project (AMEEF, 2002) as one of the most favourable sites in Australia for the development of Industrial Ecology initiatives. Apart from Alcoa's alumina refinery, the area is host to an oil refinery, a nickel refinery, a cement and lime manufacturer, a major fertiliser works, a pigment plant, a refractories manufacturer, diversified chemicals manufacturers and a range of service industries. Significant synergies already exist. As an example of a synergy that has been 'designed in' to the association of industries, the major output of Cockburn Cement's lime production is tied directly to the alumina industry. Synergies that have developed on an opportunistic basis over time include the use of spent oil refinery catalyst in the rehabilitation of bauxite residue storage areas, and the development of waste CO_2 from ammonia production as a the feed stock for the industrial CO_2 supply for the state. A future opportunity is to extend this to the direct neutralisation of bauxite residue using waste CO_2.

To further develop the synergy opportunities and provide a systematic approach, a series of meetings and workshops was held in 2001 to gain commitment to and identify opportunities for developing showcase Industrial Ecology initiatives within the KIA. Working groups have been set up in the areas of Process Waste Utilisation, General Waste Minimisation, Recycling and Re-use, and Greenhouse Gas Emission Reduction. Teams have also been set up to develop 'binary' opportunities that have been identified between pairs of industries. To progress this in 2002, the KIC has provided a co-ordination resource, and further support will be sought through the Sustainable Resource Processing Project. In addition, in 2001 the KIC commissioned Sinclair Knight Merz to provide an updated study of the economic impact of the KIA, and included identification of current and future regional synergy opportunities as a key aspect of the study. The SKM Report, which is due in early-2002, will form a key input to the work of the synergy teams.

CONCLUSION

Cleaner Production principles have been in place in Alcoa for over a decade, in various aspects of design and operation. Our challenge now is to further systematise our approach, and to quantify and report the benefits as a driver for continuous improvement. The Alcoa Business System is an ideal vehicle for Cleaner Production, and the process of integration is under way. In Western Australia, Alcoa has become a signatory to the WA Cleaner Production Statement, formalising the company's support of and commitment to Cleaner Production in that state. A recent meeting of the corporate environmental and technical functions of Alcoa endorsed the use of Cleaner Production as a guiding set of principles in the corporation's environmental program.

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