

PERENNIAL PROBLEMS – SUSTAINABLE SOLUTIONS CERAMIC ‘FIXES’ FOR INDUSTRIAL WASTE

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ABSTRACT

Rather than being dumped, some types of industrial waste can be converted into materials that are fit for use and hence have commercial value. However, truly intractable waste may still have to be dumped in which case the best practical approach is to minimise the environmental impact and cost of disposal. The concepts underlying technical ceramics and associated manufacturing processes can be adapted to achieve these various ends.

This paper discusses the definition of waste and the meaning of sustainability, in the context of waste disposal. It describes a project that illustrates how ceramic technology was applied to facilitate the use of waste. The conclusions are that materials fit for use should not be defined as waste, that sustainability must connote durability in perpetuity and that ceramics technology is a useful approach to achieving both environmental and commercial objectives in disposing of some materials that are potentially fit for use.

KEYWORDS: Industrial waste, waste reuse, definition of waste, meaning of sustainability, spent pot liner (SPL)

INTRODUCTION

There are many inert types of waste that have potential for further use but are nevertheless still dumped as land fill. Other wastes which are injurious to the environment in some way must be destroyed, for example by incineration or stored indefinitely, pending a sustainable means of permanent disposal that may as yet be unknown.

A general proposition of this paper is that knowledge of the characteristics of industrial ceramics, if not the technology itself, may lead to uses for some of these intractable materials. Developing a technological solution for the problem of industrial waste is one thing. Putting the solution into practice, that is, commercial exploitation is quite another and nearly always a more difficult feat to accomplish.

In this paper a particular project is described in detail to illustrate the technological proposition. It is a good example of how ceramics technology can be applied, of the time and resources needed to implement even a modest project and of the risk associated with such an undertaking.

The issues of financial viability, risk assessment and the myriad facets of implementation are beyond the scope of this paper. However, two issues that impinge directly on commercial exploitation are discussed because of their topicality. They are the concept of sustainability and the definition of waste itself, given the extent of government control over waste disposal and the paradox that regulations pose in protecting the biosphere.

DISPOSAL OF SPENT POT LINER (SPL)

Aluminium is won by an electrolytic process carried out in rectangular steel baths, called pots. These pots are lined with a material comprising predominantly refractory brick and carbon. The refractory material protects the steel pot from the highly corrosive molten cryolite in the bath and the carbon constitutes the cathode for electrolysis. Sooner or later the pot lining will fail, generally by cracking and must be replaced. The pots are then stripped down to the bare metal and completely re-lined. The material discarded in this procedure is called spent pot liner.

There are six aluminium smelters in Australia that generate collectively more than 40,000 tonnes per year of SPL. There is a problem with the disposal of SPL: it contains (water) soluble species of cyanide and fluoride which are definitely injurious to the biosphere. Historically, all the smelters except the one at Tomago in NSW dumped SPL on their own sites, in pits with impermeable linings. Tomago has always stored SPL in dedicated sheds. In the mid 1990s the various State Environment Protection Authorities banned this method of disposal. The dumps were capped and since then SPL has been stored on site, in sheds built specially for the purpose. Currently, the only means of permanent disposal available to Australian smelters is export to Italy. While there is a company based in Victoria that has developed a process for preparing the carbon fraction of SPL for use as fuel in making cement clinker, there is as yet no corresponding disposal route for the refractory component of SPL.

The objective of the project described in this paper was to develop a process for converting raw SPL into a non-hazardous, ceramic material which had intrinsic commercial value. Qubator Pty Ltd developed the process during the period 1989 to 1992 by contracting the scientific and technical resources of the Australian Nuclear Science and Technology Organisation (ANSTO), the Commonwealth Science and Technology Research Organisation (CSIRO) and Heat Containment Industries Pty Ltd, a company that manufactures refractory products and now known as Shinagawa Refractories Australia Pty. Ltd.

The project was funded by Alcan Australia Ltd, which at the time owned the smelter at Kurri Kurri in NSW, Alcoa of Australia Ltd which owns the smelters at Point Henry and Portland in Victoria, Tomago Aluminium Company Pty Ltd which owns the (newest) smelter at Tomago NSW and Qubator Pty. Ltd. This was reported to be the first time that these three aluminium companies had participated in and funded jointly a technological project of this type. The principal objective was to find an environmentally benign, commercially viable means of disposing permanently of SPL. Processes were also investigated during the project for recovering resources such as sodium fluoride, derived from the cryolite used in smelting aluminium but since this ancillary work does not materially impinge on the topic of this paper, it will not be recorded here in any more detail.

From a technical standpoint, Qubator's strategy was to adapt technology developed for other purposes and use equipment available in other industries rather than developing new technology from scratch. The rationale for this approach was to minimise the financial risk as well as the technical risk during development and the risk of scaling up to commercial operation. Based on theoretical work and laboratory trials carried out in 1990 during an exploratory project called SPL-1, a new project called SPL-2 was started in August 1991 to demonstrate the technology and the commercial potential of the process.

DESCRIPTION OF THE PROCESS

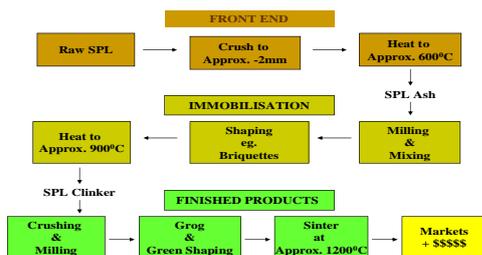


Fig. 1: General illustration of the process

Synopsis

In what is called 'the front end' process (see Fig.1), raw SPL is crushed and then heated to about 600°C in a suitable furnace, preferably a rotary calciner, to produce ash that is substantially free of carbon. The finer the ash the better for carbon combustion so autogenous grinding is an advantage. A significant amount of the energy for this part of the process is derived from the carbon itself.

The SPL ash is milled with specific precursors to achieve intimate mixing and formed into a green shape such as an extruded plank or a briquette. It is then heated to about 900°C. at which temperature any remaining cyanide is destroyed and the soluble fluoride combines with the precursors to form insoluble species. The 'clinker' that results from this part of the process is environmentally benign and may be used 'as is' or it may be converted into a finished product.

To make a finished product, the SPL clinker is crushed to make grog which is screened to produce the various fractions required to optimise the characteristics and formation of the final product. The fractions of grog are mixed in the correct proportions with a binder, if required and then pressed into net shape. The 'green' product is dried, either naturally in air or in an oven until it is strong enough to be loaded into a suitable furnace and sintered.

The Front End Process

Raw SPL from Alcan's smelter at Kurri Kurri was crushed to -2mm and spread evenly to a depth of 25mm on inconel trays measuring 1500mm by 700mm by 45mm. The trays were loaded four at a time into an electric muffle furnace at the smelter.

This technique had some disadvantages that would have become significant on the scale of full commercial operation so other methods of heating were investigated, the most effective of which was a tumble drum furnace, owned by the CSIRO at North Ryde, NSW. Trials were done in their tumble drum, rotating about its horizontal axis inside an electrically fired furnace. Raw SPL crushed to a particle size in the range >3mm and <10mm was heated to a temperature of 700°C. After 6 hours, 90% of the carbon was lost and after 24 hours, 97% carbon was lost.

Making Clinker

Making clinker involves three separate processes: preparing the ingredients, agglomeration and heat treatment.

Preparing the Ingredients

SPL ash was mixed with precursors designed primarily to combine with soluble fluoride to make

insoluble species but also to produce a durable material that has intrinsic commercial value. For the initial trials the two precursors were calcium sulphate (Ad1) and aluminium oxide (Ad2). For subsequent trials, clay (Ad3) was used in place of the aluminium oxide. Clay gave better results and is cheaper. Of the six formulations tested, details of three are given in this paper to illustrate the process.

The calcium sulphate was itself a waste material generated by Pacific Chemical Industries Pty Ltd, Sydney. It was an agglomerated powder with a particle size in the range of 50-250 microns and a nominal water content of 2wt%. The aluminium oxide was supplied by Taylor Ceramic Engineering Pty Ltd, Sydney. It was a free flowing powder calcined at 800^o C and with a particle size in the range of 5-50 microns. The dry clay used in place of the aluminium oxide was supplied by Commercial Minerals Pty Ltd as BBR - Crossley Clay which came from a quarry near Mudgee in New South Wales. The proportions of ingredients shown below were derived from formulations of the most successful laboratory samples produced during preliminary investigations of the process, which preceded this project. The formulae (by weight) are as follows (batch numbers relate to the original report on the project):

- Batch 1:- 32.5% SPL + 59.4% Ad1 + 8.1% Ad2
- Batch 2:- 33.5% SPL + 52 % Ad1 + 14.5% Ad2
- Batch 5:- 33.5% SPL + 52% Ad1 + 14.5% Ad3

SPL and Ad1 were mixed by Heat Containment Industries P/L in a 900mm diameter- Simpson mixer for 10 minutes. Ad2 and Ad3 were subsequently mixed with SPL ash and Ad1 at Qubator's premises in a 0.13 cubic metre cement mixer, also for 10 minutes.

Each batch was milled after mixing at the CSIRO Division of Exploration Geoscience, North Ryde, NSW using a 450mm diameter hammer mill such that approximately 95% of the material passed through a 100 mesh screen i.e. -150 microns.

Agglomeration

The milled ingredients were pressed dry, without binders, into briquettes measuring approximately 30mm x 20mm x 15mm. This work was done at the CSIRO Division of Coal and Energy Technology, North Ryde, NSW using a roll briquetting press made by Taiyo Machine Company of Japan fitted with horizontally opposed single cavity rolls measuring 300mm in diameter. The forming pressure applied was approximately 15 tonnes per briquette. Although briquettes were made for heat treatment because the equipment happened to be available, other forms of agglomeration would have

served the purpose just as well. For some products it may only be necessary to mix the powder into a paste and extrude it in final shape for heat treatment. Equally, if a grog were required, it would be sufficient to dry press the powder into a 'plank' or simply a cake, ready for heat treatment.

Heat Treatment

Heat treatment was carried out at Alcan in Kurri Kurri, NSW in the same muffle furnace used to produce the SPL ash. The inconel trays were lined with a refractory board approximately 20mm thick to prevent any reaction taking place between the metal and the ceramic. The briquettes were piled approximately 100mm high onto the trays.

For Batches 1 and 2, the furnace was ramped at 300^o C/hr to a temperature of 1050^o C and held at this temperature for 2 hours. For Batch 5, the furnace was ramped at 300^o C/hr to a temperature of 950^o C and held at this temperature for 2 hours. In the case of batches 1 & 2, heat treatment produced a relatively hard, buff coloured material that was very similar to the results obtained in laboratory tests carried out earlier in the project. They retained their original shape, although some were still slightly friable. The briquettes in batch 5, made using clay instead of aluminium oxide, were darker in colour and noticeably harder than those in batches 1 and 2.

Making Finished Products

Since SPL clinker is environmentally benign it can be used 'as is' for an end purpose or value can be added to the material by converting it into finished products. To do this, the clinker must be crushed, milled and screened to produce fractions of the various particle sizes that may be required to achieve optimum packing density when forming the final product. Grog is made by mixing specified proportions of the various fractions of crushed clinker with a fugitive binder and water. The grog is pressed into final shape and dried to achieve 'green' strength so that it can be loaded into a suitable furnace and sintered. Products in the form of conventional house bricks were made to illustrate this stage of the general process.

Preparing Grog

Grog was prepared at the CSIRO division of Geoscience, North Ryde, NSW. For the first trial, using material from batches 1 and 2, the clinker briquettes were crushed in a roll crusher, hammer-milled and screened to obtain particle sizes in the proportions listed below which were recommended for making bricks by the management at Heat Containment Industries.

- 42.9wt% (-4mm + 2mm)
- 9.5wt% (-0.5mm + 0.25mm)
- 27wt% (-0.25mm + 0.063mm)
- 20.6wt% (-0.063mm)

The machine operator at Heat Containment Industries who actually made the green bricks mentioned that in practice they do not prepare their ingredients and screen them according to this recommendation and his opinion was that the proportion of material (-0.25mm) was too high. Their normal practice is to use a jaw crusher to get 35-40wt% of the (-4mm +2mm) fraction, screen the residue to get 30wt% (-2mm + 0.25mm), then mill the residue to get about 35wt% of (-0.06mm) material. In view of this practice, briquettes from batch 5 were milled by the CSIRO to (-4mm) only and delivered to Heat Containment Industries for screening, ball milling, mixing and forming into bricks. They prepared grog with the following composition which in the operator's judgement was optimum for the type of material:

40wt% (-3.96mm + 1.65mm)

32wt% (-1.65mm)

28wt% ball mill (approx 70% of which -73 microns)

'Green' Brick Shaping

Heat Containment Industries made all the green bricks using a computer controlled hydraulic brick press with a single cavity which measured 231mm x 115mm. The depth of the brick was approximately 75mm, depending on how well the grog compacted under pressure. The grog was mixed in an industrial bread dough mixer.

To assist green shaping, grog derived from batches 1 and 2 was mixed with 2wt% dry Lignosol, an organic fugitive binder and 2wt% tap water. The final consistency of the mixture was determined by the operator, based on his experience. In commercial practice a solution comprising 50wt% Lignosol and 50wt% tap water would normally be used at the rate of 4wt%, rather than adding dry Lignosol to the grog first. For the bricks made from grog derived from batch 5, i.e. containing clay, the proportion of dry Lignosol was increased to 2.5wt%. Grog was prepared in lots of 10 kg, to each of which was added 650ml tap water, and the brick-press charged accordingly. The charge was subjected to the following load cycle:

Load to 18 bar - hold for 1 second to de-air;

Load to 38 bar - hold for 1 second to de-air;

Load to 56 bar - hold for 24 seconds to consolidate, Release the pressure over 4 seconds.

Sintering

The sintering temperatures and regimes were determined by experiment at ANSTO and were as follows: For the bricks made using alumina - Ramp at 180° C per hour to sinter temperature of 1150° C; hold for 5 hours; cool at 300° C/hr. In practice, a sintering temperature of 1140° C was used because this was the maximum sustainable temperature of the furnace at Kurri Kurri. For the bricks made using clay - Ramp at 180° C per hour to the sinter

temperature of 1000° C; hold for 5 hours; cool at 300° C/hr.

Analyses

Analyses were done on the materials produced at various stages of this project and its predecessor SPL-1 to monitor progress and confirm 'things were going in the right direction'. The various analyses used are as follows:

Soluble fluoride - Toxicity Characteristic Leaching Procedure (TCLP), EPA method 1311, EPA Publication SW-846, 1999, carried out by Tomago Aluminium Co.

Total fluorine - ISO 1693:1976 and analysis of the distillate by ion selective electrode, carried out by Tomago Aluminium Co.

Composition & Phase Analysis - scanning electron microscopy (SEM), X-ray fluorescence (XRF) and X-ray diffraction (XRD) techniques carried out by ANSTO.

Composition - XRF-fusion and a wet chemical process for the Sulphates carried out by ACI Ltd.

Density and Porosity - geometric and Archimedean methods carried out by ANSTO.

Wear - ANZS 4456 carried out by Boral Laboratories P/L.

Transverse strength - AS1226.3, carried out by Boral Laboratories P/L

Compressive strength - AS1226.4, carried out by Boral Laboratories P/L

Water absorption - AS1276.9, carried out by Boral Laboratories P/L

Resistance to salt attack - AS3542 (Draft), carried out by Boral Laboratories P/L

Results

Apart from some physical characteristics, the only result that relates directly to the principal objective of the project is the immobilisation of soluble species in the final product, that is, fluorides in the bricks, the cyanides having been volatilised during the 'front end' process.

Leachate analysis of four bricks made with alumina (Batch 1) gave an average level for soluble fluoride of 13.25 mg/l (+/-0.75mg/l). Analysis of four bricks made with clay (Batch 5) gave an average level for soluble fluoride of 15.25 mg/l (+/- 0.75mg/l). These results are an order of magnitude below the minimum regulatory requirement of 150mg/l. They are comparable to those obtained during SPL-1 for ceramic made using raw SPL supplied by the smelters at Kurri Kurri, Tomago, Gladstone, Point Henry and Portland, thereby demonstrating the general applicability of the process. The same four bricks from each batch mentioned above were analysed for total fluoride which yielded average results of 7wt % (+/- 0.2%) and 6.1wt % (+/- 0.4%) respectively. These results are also comparable to those obtained during SPL-1 and tend to corroborate the general conclusion that SPL from

all the other sites in Australia can be treated successfully by this process.

Financial analysis

The emphasis of this paper has been on the technical development of a solution to an industrial problem. However, its commercial viability also depends on being financially attractive when compared with alternative solutions. In the early 1990s the alternatives comprised dumping on site or storing in sheds, which at the time cost about AUD \$500,000 each to build and were able to accommodate two to three years output. There was at the time no concept of exporting SPL for final disposal.

Clearly, a process cannot compete financially with dumping on site but it was well understood by the management of the aluminium smelters that dumping was not a sustainable practice in any sense of the phrase. The cheapest options being used overseas for disposing permanently of SPL, e.g. by Reynolds in the USA, cost an equivalent of at least AUD\$500/tonne. It is noted that this is comparable to the 'gate fees' currently paid to cement factories in Australia for accepting SPL and is half the cost of shipping SPL to Italy for permanent disposal. Based on the results obtained during SPL-2 and assuming a simple product was manufactured such as a house brick, the production cost of Qubator's process was estimated at the time to be AUD\$300/tonne.

Epilogue

Although the results of SPL-2 demonstrated that the process would be commercially viable, the project came to a halt in the middle of 1992 and was abandoned soon after. The recession that had just started in Australia at that time inhibited enthusiasm for technological development with the result that funding for SPL-3, the next stage of the project, collapsed. Alcoa alone considered further work on the process. However, their resources for development projects were severely curtailed and stimulated by the recession, they were beginning to focus more on reclaiming sodium fluoride. They opted to continue funding a different project, the principal objective of which was to reclaim useful materials from the waste rather than permanent, sustainable disposal of the waste.

By the time the effects of the recession had dissipated and interest in Australian R&D had revived, the original scenario had changed irretrievably. The ownership of Alcan had changed and people had moved on; Alcoa were pre-occupied with resource reclamation and Tomago adopted a policy of relying on third party services for disposal, thereby obviating any exigence to be involved directly in developing a solution to the problem of disposal.

At the moment, export to Italy is the only option for permanent disposal but it costs about \$1000/ tonne and is generally regarded as fundamentally unsustainable. As noted earlier, there is a company based in Victoria that has been developing a process to extract the carbon from SPL so it can be used as a fuel in making cement. The process is ready for commercial operation, pending completion of third party negotiations. There is as yet however no disposal route for the refractory component of SPL although that same company is currently working on this issue.

DEFINITION OF INDUSTRIAL WASTE

Had the SPL projects progressed to commercial exploitation as originally planned, the process would have been owned by Qubator but operated under licence by the smelters themselves or by independent contractors, supplying a service to the smelters. SPL in this scenario is far from being a waste product. In fact, it is the raw material for a legitimate commercial enterprise.

Although commercial exploitation did not eventuate at the time, the scenario does illustrate the circumstances that arise increasingly as the trend gains momentum towards using industrial waste rather than dumping it. Particular issues evolving from this trend are the definition of waste itself and the significance of that definition in the context of government regulation.

From an analysis of what happens in practice, both in government and industry, it is reasonable to conclude that a common definition has evolved of what constitutes waste. However, the definition serves two conflicting and fundamentally different purposes with regard to the position of an industrial enterprise, that is, the generator of waste on the one hand and the position of Government on the other.

During the course of its normal operations, an industrial enterprise, construed in this context to be one operating on a single site, may discard materials that range from obsolete and rejected raw material through materials scrapped during production, processing waste such as sweepings, bag-house dust and effluent from cleaning in place (CIP), to scrap products.

Fundamentally, an industrial enterprise regards as waste anything it discards and hence needs to have removed from site. The issue of waste then becomes a question of disposal and in this context the usefulness of the waste is a significant factor. Broadly stated, there are four options for disposal. The generator might be able to sell the waste, which would usually then be called a by-product; it might be able to give the waste away; it may have to contribute to the cost of removal for some further use off site otherwise the generator will have to pay

the full cost of removal and dumping. Given the focus of this paper, only the option of dumping will be analysed further.

An enterprise will try to dispose of waste as cheaply and as effortlessly as possible. Disposal is not regarded as an integral or 'core' part of a generator's business. The Environmental Defender's Office is one of many sources of evidence to show that enterprises would gladly dump waste willy-nilly, if that were allowed to happen.

(See

<http://www.edo.org.au/edonsw/site/policy/ipart060224.php>)

Governments on the other hand, are the only institutions that are capable of preventing the indiscriminate dumping of waste and hence ultimately they are the only institutions that have the potential to protect the biosphere. The willingness and/or power of individual Governments around the world to exercise this potential vary greatly but a comprehensive analysis of government behaviour with respect to the biosphere is beyond the scope of this paper. However, the current situation in New South Wales appears to be typical of what is happening in other jurisdictions in Australia and is certainly a good illustration of the dilemma posed by the paradox of regulation.

As a statement in general terms of the situation, one horn of the dilemma is this: Governments have to promulgate definitions of waste that include everything discarded by an industrial enterprise so that their regulators such as an Environmental Protection Agency (EPA) can control the disposal of waste as much as possible. Whatever the law defines as waste, the EPA has the power to control and this they do by imposing stringent rules, requirements and penalties regarding the disposal of waste.

One form of the control exercised by an EPA is to set a 'floor price' for the cost of disposal. This they do by such measures as regulating the fees for access to land fill, restricting the types of material that can legally be accepted at land fill sites and requiring that specific means of disposal be used for particular types of industrial waste. It seems that to a regulator the words disposal and dump are synonyms.

Another form of the control is to classify waste in categories that broadly correlate with its potential to harm the biosphere. The categories range in character from those deemed harmless to highly toxic and each is subject to some form of regulation with respect to disposal.

The other horn of the dilemma is that industry at large has to be aware of the regulations and to comply with them. Doing so involves resources, time, patience and a generally perceived risk of contravention or misinterpretation.

Herein lies the paradox: Regulations that are necessary to protect the biosphere can act to inhibit initiatives to develop uses for industrial waste.

As has happened in the author's experience, if initiatives to find uses for waste are not undertaken by enterprises because they do not have the capacity to comply with regulations that may in fact be unnecessary in the circumstances, then the fundamental purpose of the legislation to protect the biosphere will have been frustrated.

By way of illustrating the paradox, the New South Wales Department of the Environment and Climate Change provides the following definition of waste, which can be found at http://www.epa.nsw.gov.au/resources/waste_guide.pdf:

Waste: As defined in the Waste Minimisation and Management Act 1995 and the Protection of the Environment Operations Act 1997:

'waste includes:

- (a) any substance (whether solid, liquid or gaseous) that is discharged, emitted or deposited in the environment in such volume, constituency or manner as to cause an alteration in the environment, or
- (b) any discarded, rejected, unwanted, surplus or abandoned substance, or
- (c) any otherwise discarded, rejected, unwanted, surplus or abandoned substance intended for sale or for recycling, reprocessing, recovery or purification by a separate operation from that which produced the substance, or
- (d) any substance prescribed by the regulations to be waste for the purposes of this Act.

A substance is not precluded from being waste for the purposes of this Act merely because it can be reprocessed, re-used or recycled.'

Authorities in other Australian jurisdictions (e.g. Victoria) have promulgated similarly comprehensive definitions of waste and corresponding regulations, sanctions and penalties associated with them. Part (c) and the last sentence of this general definition are particularly significant in the context of using waste. By subjecting usable materials to regulations that are only appropriate for useless materials, that is, genuine waste that has to be dumped, the Government is inhibiting precisely those initiatives that tend to alleviate pressure on the biosphere.

It is not suggested that dealing with toxic materials such as SPL should be completely unfettered; that would be an untenable position, given the

inclinations of industrial enterprises already mentioned. However, demonstrably usable waste is also subject to stringent regulations that are not necessary in the circumstances.

A case in point is a project undertaken by the author to find a use for 5 tonnes (dry weight) a day of shredded low density polyethylene (LDPE) film, coated with aluminium, which arose from recycling high grade paper containers. The plant at which the paper was recovered used coal for boiler fuel but could not burn the plastic because of its form. It took eighteen months to develop briquettes made from the scrap plastic, mixed with scrap coal that could be burnt in the furnace. The project was abandoned by the company when they realised that the costs of preparing an environmental impact statement and the annual review required by the EPA made the economic return on the project so marginal that it was not worth their while going to the trouble of installing and maintaining the equipment. The biosphere very definitely suffered in this case from the exigencies of un-necessary regulation. The contention is that regulations should be and can be made more conducive than they currently are to developing and exploiting potential uses for waste.

One approach to alleviating the paradox is to regulate the disposal of waste by reference to what is done with it rather than by reference to its origin, as is currently the case. In such a scenario, any material for which there is a present and demonstrable use would be subject only to the regulations that pertain to the trade of normal products in the same or a similar class of goods. It is contended that simply to remove the possibility of infringing environmental regulations would stimulate initiatives to use waste that otherwise would not have been attempted. Another approach that would achieve much the same benefits is to define a class of materials that may have been rejected for one purpose but may yet be useful for another. Materials in this class should be treated by the regulators as if they were normal products such as raw materials and finished goods rather than as the waste materials they are currently taken to be.

DEFINITION OF SUSTAINABILITY

The current situation with regard to the disposal of SPL is an excellent context in which to analyse the notion of sustainability. If the refractory component as well as the carbon component of SPL could be used in making cement, then doing so would certainly be a permanent means of disposal. However, sustainability is not at all certain, principally for the reason that in this paradigm, a generator of waste depends entirely on third parties for the success of its disposal strategy. Being entities at arm's length, it is totally beyond the power of the generator to guarantee the continuing existence of those third parties for the duration of its

own commercial life. In the sense of being sustainable, this waste disposal strategy is weak.

The countervailing paradigm is where the generator retains control over the entire system of disposal. For example, the SPL project developed a process that was designed to be operated by each aluminium smelter itself, on its own site, as if it were an integral part of its normal operations. The smelters had the option of re-using the ceramic themselves or selling finished products. This is a much stronger strategy and has a correspondingly better potential for achieving sustainability

In assessing the value of these paradigms, one has to deal with the question of what exactly is meant by the word sustainable and its related epithets. There seem to be as many meanings for these words as there are contexts in which they are used. There is however a clear distinction between the meaning to maintain or support and the meaning of durability. In the context of waste and its impact on the biosphere, it is contended that the word and its relations should very definitely be construed to imply the notion of durability, specifically, in perpetuity.

One approach to understanding the notion of sustainability is to assess the risk that some action, strategy or thing is in fact un-sustainable. A good way of doing this is to consider three distinct scenarios for sustainability: technical, commercial and longevity.

Technical sustainability

The technical scenario includes such issues as the durability of a process that might be used to deal with waste and the reaction of waste in the various environments to which it might be subjected. For as long as one mixes SPL ash with calcium sulphate and clay, the fluoride will become almost insoluble and the resulting material will remain environmentally benign, effectively in perpetuity. Ceramics technology does that job very well so one can reasonably say that the process is technically sustainable.

Commercial sustainability

The same may not so confidently be stated about the availability of calcium sulphate and/or clay and this uncertainty relates to the commercial scenario.

As it happened, the calcium sulphate used in the SPL project was itself a waste material arising in Sydney. However, the factory stopped producing the stuff in the mid 1990s. If calcium sulphate were not available from another source or a substitute could not have been found the disposal strategy would have been decidedly un-sustainable but for commercial rather than technical reasons.

The Commercial scenario also includes the question of what to do with the waste material either in its original state or after processing. Dumping is pretty much out of the question, unless of course, there is Government support for that option. A fundamental characteristic of all free market economies is that demand (for a good or service) might be adversely influenced by almost anything that could happen. This characteristic alone makes inherently unsustainable any disposal strategy that depends entirely on free market forces alone.

Longevity

The concept of durability is perhaps the most salient characteristic of sustainability. Although it may be thought that a disposal strategy need only be effective for as long as the waste is being generated, it is fundamental to the whole concept of sustainability that no material ever poses a threat to the biosphere. The results of a disposal strategy must therefore be durable, in perpetuity.

For example, using SPL to make Portland cement satisfies this condition of longevity. If, however, it were possible for the fluoride in SPL ceramic to become leachable again sometime in the future and so pose a toxic threat to the biosphere then the material would not be durable, in perpetuity and the strategy should not be regarded as sustainable. In the context of longevity, it is noted that the TCLP test for leachable fluoride is carried out over a relatively short period of only 16 hours.

Assessing the sustainability of a disposal strategy in theory is one thing; actually finding uses for industrial waste in practice is another matter. The author's experience is that simply being able to rescue waste from a dump site is difficult enough without having to cope also with the exigencies of sustainability. Nevertheless, sustainability is undoubtedly what has to be achieved in practice even though it may not be accomplished at the first attempt. It would be safe to assume that a given solution to a problem is unlikely to be the ultimate solution. It is axiomatic that there will probably be a better way of using waste than the current one. In this context the nuance of sustainability that implies maintenance or support is relevant in the sense of a continuing process to improve the status quo.

CONCLUSIONS

The principal value of ceramics technology in dealing with certain types of industrial waste is its capacity to produce a sustainable means of disposal. Even if the technology itself is not used, thinking in 'terms of ceramics', that is combining different, sometimes dissimilar materials and processing them to form a final, useful product can often be a fruitful approach to dealing with waste.

There are real, practical difficulties arising from the definitions of waste promulgated by Governments.

These difficulties do inhibit the reuse of waste, which is the antithesis of what is intended by the regulators. There are ways to overcome these difficulties but they necessitate government co-operation and that may take a fair bit of effort to achieve.

The SPL project described in this paper provides a context for defining an unequivocal meaning of sustainability and its related epithets as they apply to the disposal of industrial waste. The notion of durability in perpetuity is shown to be fundamental to the concept of sustainability.

It is contended in this paper that sustainable waste disposal strategies are likely to be complicated and difficult to achieve in practice. Strategies will almost certainly have to be multi-faceted in order to be sustainable. Although strategies may well be imperfect in theory, implementing an imperfect strategy with a view to improving it is better than having no strategy at all and dumping the waste instead.