Centre for
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Project 3B3: Kwinana Industrial Inorganic By-Product Reuse

Market Assessment for the Reuse of Inorganic Industrial By-products in the Kwinana Industrial Area

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EXECUTIVE SUMMARY

Various mineral processing operations produce large volumes inorganic residues that are currently stockpiled at designated locations within the Kwinana Industrial Area (KIA). A significant number of these have potential value as useful by-products for various commercial, particularly infrastructure, applications. Many of the inorganic residues generated within the KIA could be utilised as alternative or supplemental sources for the growing demand for construction materials providing these meet specific environmental criteria and technical specifications.

The report reviews the KIA generated inorganic by-products and ten different residues are discussed, outlining there potential uses. The residues identified are: fly ash, bottom ash, direct iron making slag, phosphogypsum, foundry sand, construction and demolition debris, cement kiln dust, lime kiln dust, red lime, and red sand. Their impressive assortment of application ranges from concrete additives through use in variety of civil engineering works, to agricultural application.

The market assessment has identified a number of imminent and planned infrastructure, residential and commercial development projects within a reasonable distance from KIA (approximately 20 km) to assure economic viability for the potential reuse of inorganic materials generated within the KIA. One of, if not the biggest, potential issues related to the reuse of inorganic by-product/waste materials as useful substitutes for virgin materials however is the lack of a regulatory frameworks and suitable standards to enable the routine utilisation of these by-products in commercial infrastructure and development projects.

The need for imported clean fill and various construction materials for the examined projects is as follows (approximate quantities):

- James Point Port, Stage 1 – 0.3 Mt fill and 3. Mt materials;
- Kwinana Quay Project – depending on the option to be chosen, 7-22.4 Mt fill and 3.6 – 4 Mt materials;
- Kerralup –0-10 Mt fill and 1 Mt road materials;
- Wungong Urban Water - 16.5 Mt fill and 0.4 Mt road materials;
- Latitude 32 and many other projects with unknown quantities for imported fill and construction materials.

The total estimated requirement for the project that can be quantified at present is in the excess of 40,000,000 tonnes of imported fill and in excess of 10,000,000 tonnes of construction materies.

High level economic assessment was carried out only for one of the ten KIA inorganic residues, as a case study. Red sand was chosen for this assessment due to the extensive work carried out by Alcoa for that by-product, thereby enabling access to more accurate data required for the analysis. Various technical, economical and sustainability issues were taken into consideration and have lead to the spontaneous conclusion that the red sand is a product that has acceptable technical characteristics, and provides a wide range of sustainability benefits when used as a replacement for virgin sand in infrastructure projects. Red sand is expected to be economically competitive as well, and its convenient location to some of the upcoming major civil engineering projects makes it a valuable material. Prices for natural materials and associated transport are only expected to increase in the future, leading to an increased attraction regarding the use of inorganic by-products, assisting with focusing end-user's attention on alternative materials.

This paper recommends that the CSRP and KIC proactively, and quickly, commence work with the Western Australian Government to develop the relevant regulatory framework and standards to enable the reuse of inorganic by-products in infrastructure projects. Using the range of existing regulatory frameworks and standards that already exist in other countries these could be developed relatively quickly for Western Australia, or Australia as a whole. This includes a standard, similar to the European EN 12920, for characterisation of waste.

Concurrently with this, CSRP and the KIC should undertake research to develop the required beneficiation methods and equipment to prepare the materials to the required standard and specifications. A number of trials, or demonstration projects should be undertaken, in conjunction with the relevant Government agency, using the materials in a range of infrastructure applications.

Research should also be undertaken to assess the life-cycle sustainability benefits (or otherwise) of reusing inorganic by-products compared to using virgin conventional materials. This could produce a number of case studies that could inform Government and the community about the sustainability benefits of using these materials.

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1. MARKET ASSESSMENT FOR USE OF KIA INORGANIC RESIDUES

Various mineral processing operations produce large volumes of inorganic residues, which are currently stockpiled at designated locations. A significant number of these have potential value as useful by-products for use in various commercial applications. The CSRP has registered a generic trade mark, ReSand^{TM} to collectively describe these materials (Bagshaw 2007).

The purpose of this assessment is to establish the potential demand for the reuse of ReSand^{TM} materials generated within the Kwinana Industrial Area (KIA) over a certain time period, and within a limited geographical proximity. The assessment is prompted by the increasing difficulties in obtaining large volumes of basic raw materials in recent years for buildings and infrastructure projects. There is expected to be an escalated demand in the short to midterm future, prompted by the announcements of numerous large-scale commercial and residential developments in the region.

While the use of the inorganic by-products is in general terms, the potential demand is assessed on a local basis taking into account the proposed engineering and development projects discussed in Section 1.2. No particular data is available for the majority of the discussed inorganic by-products, resulting in a rather superficial review of the market opportunities without employing detailed information. As more detailed information becomes available more in-depth analysis can be undertaken.

1.1. Local supply

1.1.1. Fly Ash

The fly ash produced from the burning of coal in a coal-fired boiler is a fine-grained, powdery particulate material that is carried off in the flue gas and usually collected from the flue gas by means of electrostatic precipitators, baghouses, or mechanical collection devices such as cyclones.

In general, there are three types of coal-fired boiler furnaces used in the electric utility industry. They are referred to as dry-bottom boilers, wet-bottom boilers, and cyclone furnaces. The most common type of coal burning furnace is the dry-bottom furnace.

When coal is combusted a large percentage of all the ash leaves the furnace as fly ash, entrained in the flue gas. The remaining ash is bottom ash, a dark gray, granular, porous, predominantly sand sized material that is collected in a water-filled hopper at the bottom of the furnace.

The fly ashes produced in Australian power stations are light to mid-grey in colour and have the appearance of cement powder. Particle sizes range from less than 1 µm (micrometer) to 200 µm and are irregular to spherical in shape. In Australia the majority of ash produced is categorised as Class F waste, being mainly silica and alumina (80-85%), and >10% Calcium Oxide. Class F ash is highly pozzolanic and reacts with various cementitious materials (ADAA 2007).

1.1.1.1. Qualitative/quantitative information

At this point in time Kwinana power station has stockpiled about one million tonnes of fly ash as a result of 20 year operation. In addition a significant amount of bottom ash is stockpiled (about 1/3 the size of the stockpiled fly ash). The fly and bottom ash are stockpiled and managed separately.

Some of the fly ash is currently used for brick manufacturing. The University of WA has also conducted research on the reuse of fly ash as a soil conditioner on turf farms. In the past, fly ash (from the Muja power station) has also been used in concrete road barriers produced by Boral Concrete.

1.1.1.2. Potential uses (FHWA 1998) (ADAA 2007)

- Portland Cement Concrete – Supplementary Cementitious Material

In other places in the world fly ash has been successfully used as a mineral admixture in Portland Cement Concrete (PCC) for nearly 60 years. This is the largest single use of fly ash. It can also be used as feed material for producing Portland cement and as a component of a Portland-pozzolan blended cement.

- Asphalt Concrete – Mineral Filler

Fly ash has been used as substitute mineral filler in asphalt paving mixtures for many years. Mineral filler in asphalt paving mixtures consists of particles, less than 0.075 mm in size, that fill the voids in a paving mix and serve to improve the cohesion of the binder (asphalt cement) and the stability of the mixture. Most fly ash sources are capable of meeting the gradation (minus .075 mm) requirements and other pertinent physical (nonplastic) and chemical (organic content) requirements of mineral filler specifications.

- Stabilised Base – Supplementary Cementitious Material

Stabilised bases or sub-bases are mixtures of aggregates and binders, such as Portland cement, which increase the strength, bearing capacity, and durability of a pavement substructure. Because fly ash may exhibit pozzolanic properties, or self-cementing properties, or both, it can and has been successfully used as part of the binder in stabilised base construction applications.

Fly ash is widely used in the binder component of roadbase mixtures, and in 5 MPa concrete sub-base in NSW. At Port Augusta Power Station, roads and covers over coal stockpiles have been constructed successfully using cement bound mixtures of fly ash and furnace bottom ash. Queensland Transport requires the use of fly ash in concrete used in roads and bridges as insurance against alkali-silica reaction (ASR).

- Flowable Fill – Aggregate or Supplementary Cementitious Material

Flowable fill is a slurry mixture consisting of sand or other fine aggregate material and a cementitious binder that is normally used as a substitute for a compacted earth backfill. Fly ash has been used in flowable fill applications as a fine aggregate and (because of its pozzolanic properties) as a supplement to, or replacement for, the cement. Either pozzolanic or self-cementing fly ash can be used in flowable fill. When large quantities of pozzolanic fly ash are added, the fly ash can act as both fine aggregate and part of the cementitious matrix. Self-cementing fly ash is used in smaller quantities as part of the binder in place of cement.

The quality of fly ash used in flowable fill applications need not be as strictly controlled as in other cementitious applications. Both dry and reclaimed ash from settling ponds can be used. No special processing of fly ash is required prior to use.

- Embankment and Fill Material

Fly ash has been used for several decades as an embankment or structural fill material, particularly in Europe. There has been relatively limited use of fly ash as an embankment material in USA, although its use in this application is becoming more widely accepted.

As an embankment or fill material, fly ash is used as a substitute for natural soils. Fly ash in this application must be stockpiled and conditioned to its optimum moisture content to ensure that the material is not too dry and dusty or too wet and unmanageable. When fly ash is at, or near, its optimum moisture content, it can be compacted to its maximum density and will perform in an equivalent manner to well-compacted soil.

- Agriculture

There are conditions where fly ash and furnace bottom ash can be used to improve soils for agriculture. Heavy clay can be lightened at one extreme and sandy soil can be given body and increased water retention properties at the other.

The Ash Development Association of Australia (ADAA) are joint research sponsors with the University of Western Australia of a four year test program looking at the application of fly ash to soils. The research program which is being conducted in Western Australia, has already demonstrated substantial improvement in water retention and pasture growth in sandy soils.

Some of the findings have highlighted fly ash’s ability to improve water retention in soils with low moisture holding capacity (i.e. sandy soils) to over 30% compared to untreated soils. Furthermore fly ash provided increased plant growth without the need for additional fertilizers.

- Waste treatment and Fixation

Fly ash finds a use both as a reactive absorbent for industrial waste liquors and as a component of containment concretes. ADAA are reviewing the potential for this use prior to providing appropriate fixation advice for Australia.

- Chemical Source

The technical literature abounds with schemes for removal of alumina and other materials from fly ash. Magnetite removal has been done on a commercial scale from fly ash rich in iron. Conversion of fly ash to more reactive zeolites shows promise for enhanced performance as a pozzolan and for noxious waste fixation and effluent treatment.

1.1.2. Bottom Ash

Coal bottom ash is the coarse, granular, incombustible by-product that is collected from the bottom of furnaces that burn coal for the generation of steam, the production of electric power, or both. The most common type of coal-burning furnace in the electric utility industry is the dry, bottom pulverized coal boiler. When pulverized coal is burned in a dry, bottom boiler, about 80 percent of the unburned material or ash is entrained in the flue gas and is captured and recovered as fly ash. The remaining 20 percent of the ash is dry bottom ash, a dark gray, granular, porous, predominantly sand sized material that is collected in a water-filled hopper at the bottom of the furnace. When a sufficient amount of bottom ash drops into the hopper it is removed by means of high-pressure water jets and conveyed by sluiceways either to a disposal pond or to a decant basin for dewatering, crushing, and stockpiling for disposal or use.

1.1.2.1. Qualitative/quantitative information

See section 1.1.1.

1.1.2.2. Potential uses (FHWA 1998) (ADAA 2007)

Leading bottom ash applications are snow and ice control, as aggregate in lightweight blocks, and raw feed material for the production of Portland cement. Bottom ash has also been used as a road base and sub-base aggregate, structural fill material, and as a fine aggregate in asphalt paving and flowable fill.

- Asphalt Concrete Aggregate

  Bottom ash can be used as a fine aggregate substitute in hot mix asphalt wearing surfaces and base courses, and emulsified asphalt cold mix wearing surfaces and base courses. Because of the “popcorn,” clinker-like, low durability nature of some bottom ash particles bottom ash has been used more frequently in base courses than wearing surfaces.

  Screening of oversized particles and blending with other aggregates will typically be required to use bottom ash in paving applications. Pyrites that may be present in the bottom ash should also be removed (with electromagnets) prior to use. Pyrites (iron sulfide) are volumetrically unstable, expansive, and produce a reddish stain when exposed to water over an extended time period.

- Granular Base

  Bottom ash has occasionally been used as unbound fine aggregate or granular base material for pavement construction. To meet required specifications, the bottom ash needs to be blended with other natural aggregates prior to its use as a base or sub-base material. Screening or grinding may also be necessary prior to use, particularly for the bottom ash, where large particle sizes, typically greater than 19 mm (3/4 in), are present in the ash.

- Stabilised Base Aggregate

  Stabilised base or sub-base mixtures contain a blend of aggregate and cementitious materials that bind the aggregates, providing the mixture with greater bearing strength. Types of cementitious materials typically used include Portland cement, cement kiln dust, or pozzolans with activators, such as lime, cement kiln dust, and lime kiln dust. When constructing a stabilised base using bottom ash, both moisture control and proper sizing are required. Deleterious materials such as pyrites should also be removed.

- Embankment or Backfill Material

  Bottom ash could be used as structural fill materials for the construction of highway embankments and/or the backfilling of abutments, retaining walls, or trenches. To be suitable for these applications, the bottom ash must be at or reasonably close to its optimum moisture content, free of pyrites and/or “popcorn” like particles, and must be non-corrosive. Bottom ash may require screening or grinding to remove or reduce oversize materials.

- Flowable Fill Aggregate

Bottom ash has been used as an aggregate material in flowable fill mixes. Since most flowable fill mixes involve the development of comparatively low compressive strength (in order to be able to be excavated at a later time, if necessary), no advance processing of bottom ash is needed. The bottom ash does not need to be at any particular moisture content to be used in flowable fill mixes because the amount of water in the mix can be adjusted in order to provide the desired flowability.

1.1.3. Direct Iron Making Slag

Slag is produced in the iron smelting process due to the reaction between the flux, the gangue in the ore and the ash in the coal.

1.1.3.1. Qualitative/quantitative information

Depending on the source of the raw materials and process conditions, approximately 250-300 kg of slag is generated per tonne of hot metal. This is expected to result in an annual production of 225,000 tpa of slag for the 800,000 tpa HIsmelt plant (stage 1). The slag is expected to have properties similar to those of blast furnace slag (BFS), which traditionally have been used as an aggregate for concrete or road base applications.

1.1.3.2. Potential uses (HIsmelt 2002)

Slag can be granulated or directed into pits for further processing. It can then be used as a raw material for a variety of purposes such as cement manufacture, road base and soil conditioning.

- Aggregate

To produce slag suitable for use as an aggregate, it is necessary to slowly cool the slag to allow the mineral phases to crystallise. Slow-cooled slag has similar properties to rock; therefore it can replace material currently supplied by hard rock quarries.

- Substitute for clinker

Rapidly quenching the slag with water results in a granulated slag with vitreous (glassy) properties. Granulated slag has good hydraulic properties and can be used as a substitute for clinker in the production of Portland cement. The ground slag can be introduced and milled with the cement feedstock or blended separately after the cement is ground to its required fineness.

1.1.4. Phosphogypsum

Calcium sulphate dihydrate ($CaSO_4.2H_2O$) is a basic component of chemical gypsums which vary depending on the primary manufacturing products created during chemical processing. Phosphogypsum is the most common of the by-product gypsums. It is produced in fertilisers plants as a result of the reaction between sulphuric acid and natural phosphorites.

1.1.4.1. Qualitative/quantitative information

Phosphogypsum was produced in the KIA as a by-product from phosphoric acid production between 1982 and 1986. Production and disposal ceased in 1986, but significant quantities of gypsum are still stored on-site. A total of 1.3 million tonnes of gypsum are stockpiled on-site (Wellard Road).

Some of CSBP's gypsum is utilised by Alcoa's alumina refineries to assist in plant growth and soil stability in its residue areas. Alcoa takes this material on an ongoing basis, approximately 10,000 tonnes each year.

CSBP is working with a company to blend gypsum with lime for reuse as soil conditioner, which facilitates the use of much larger quantities of the gypsum.

In the past CSBP conducted some work on the reuse of gypsum in bricks and plasterboard. However, gypsum tends to slightly discolour the produced plasterboard (grey colour). There is a consumer perception that this discolouring compromises the quality of the plasterboard. There might be an opportunity to blend in the phosphogypsum from CSBP with natural gypsum to reduce or prevent the discolouring of the plasterboard.

1.1.4.2. Potential uses (Bossilkov et al. 2008)

- Use in construction materials

  Phosphogypsum can be used to produce plasterboard and also to be blended in bricks. It can also be used as a set controlling agent in the production of Portland and blended cements.

- As feedstock for chemical processing

  There are a number of examples of phosphogypsum being utilised as a raw material for the production of a variety of chemicals, such as ammonium sulphate, sulphuric acid and also used in a process to produce nitric fertiliser and lime.

- For soil amendment

  Gypsum is used to combat alkalinity and salinity and is particularly effective on soils having a high sodium concentration. Specifically, the physical properties of these soils, especially permeability, are improved by using gypsum. Phosphogypsum is also widely used mainly in arid areas, for the treatment of alkaline soils and for the treatment of saline soils in irrigated areas.

1.1.5. Foundry Sand

Foundry sands are primarily silica sands although occasionally olivine, chromite and zircon sands are used in small amounts because of their unique refractory properties. Some sources of sand naturally contain a relatively high content of up to 500ppm of fluoride. Foundry sand by-products can contain metal pieces (tramp metal) and residual binding compounds. Chemical binders can limit the re-use options because of their potential for causing environmental harm.

Apart from tramp metal, the principal contaminants include phenols, formaldehyde, urea and fluoride. Concentrations of these contaminants will vary depending on the stage of the process and location in the mould. For example, reject cores will contain significant concentrations of chemical binder whereas much of the chemical binder from sands immediately adjacent to the molten metal is lost (EPA 1999).

1.1.5.1. Qualitative/quantitative information

Foundry sand is generated as a by-product at a rate of 18,000 tones pa at the Bradken mining foundry at Henderson.

1.1.5.2. Potential uses (FHWA 1998) (EPA 1999) (URS 2001)

Compared to other types of sand by-products foundry sands might not be readily reusable due to the contamination with various binding agents.

- Asphalt Concrete and Flowable Fill Aggregate

  In USA foundry sand has been used as a substitute for fine aggregate in asphalt paving mixes. It has also been used as a fine aggregate substitute in flowable (or controlled density) fill applications. Prior to use, spent foundry sand requires crushing or screening to reduce or separate oversized materials that may be present. Stockpiles of sufficient size typically need to be accumulated so that a consistent and uniform product can be produced (i.e., day-to-day variations in the material characteristics can be overcome by blending in a comparatively large stockpile).

- Feedstock for cement production

  The foundry sand contains silica, alumina and iron oxide, which are key ingredients of cement. The process of manufacturing cement requires heating to more than 1300º which destroys any organic binder components in the sands. Cement kilns have often been proposed as an ideal means of thermally destroying organic by-products, so the organic components of spent foundry sand would pose little concern.

- Concrete Aggregate

  Any by-products used in cement production ultimately will end up in concrete products and construction. In addition, some foundry sands might be suited to mix with cement to produce various concrete products. Foundry sand use in concrete has been approved in various states of America. In 1992 New York State approved foundry sand concrete in flat work. Restrictions included record keeping, reporting, and a sampling and analysis plan to ensure the sand does not change over time.

- Bricks

  Foundry sand can be incorporated into baked clay bricks. The very fine dust collected in baghouses might be useful as a colouring agent in concrete and fired products.

- Hot mix asphalt

  In many countries the use of spent foundry sand as an aggregate in hot-mix asphalt is a common practice. The major concern of the asphalt industry is the product consistency and adequate supply. Green sand does not appear to have a potential use in asphalt due to its clay content. Any residual hydrocarbons in the foundry sands could be expected to be insignificant when compared with the background levels of hydrocarbons in the asphalt.

- Granulation (pelletisation)

  Pelletising of green sand and baghouse dust to a ceramic finish could be an option for use in filters for ponds or decorative pebbles, with any residual contaminants fixed within the pebble matrix.

- Landfill cover

Many foundry sands might be suitable as daily cover for landfill. This option is a lower priority to the other beneficial re-uses discussed.

- Construction fill

Foundry sands might be suitable for use as fill material on construction sites provided they do not contain contaminants at concentrations that would result in the land becoming contaminated land, and its physical characteristics are compatible with the intended use.

1.1.6. Construction and Demolition Debris (C&D)

1.1.6.1. Qualitative/quantitative information

C&D covers waste materials which arise from the construction and/or demolition of buildings and civil engineering infrastructure. It consists of either segregated, or mixed, unprocessed and uncrushed materials, particularly, concrete, bricks, tiles, asphalt, etc.

The majority (88% or 427,400 tonnes in 2005/06) of the recovered C&D material in Western Australia is sourced from the commercial sector, (Cardno BSD 2007) with the remainder attributed to government, municipal and landfill operators.

In the vicinity of the KIA there are large volumes (millions of tonnes) of C&D material which are currently landfilled at the corner of Thomas and Rockingham Roads and managed by Waste Stream Management.

1.1.6.2. Potential uses

The main market for recovered C&D products are aggregates, road base and fill for private contractors, where the reprocessed material competes directly with virgin products. Recycled brick companies sell their material for paving and building applications.

Rubble can be crushed and used as fill, roadbase and drainage aggregates. Bricks and tiles can be recovered and reused in many instances where they are still in good condition. A number of companies clean bricks for reuse, although they require bricks made prior to 1955 due to the types of mortar used in construction. Damaged bricks can also be recycled through crushing and used as raw materials in the manufacture of new bricks. Tiles can be crushed along with other waste and used as fill, drainage aggregate or roadbase. Concrete can also be crushed and used as fill, roadbase, non-structural concrete items such as kerbing, as well as drainage aggregate (WAWMB 2006).

At present it is often more economical to send C&D waste material to an inert landfill for disposal rather than to a C&D recycling facility. This is due to the low gates fees and their competitive locations throughout the Perth metropolitan area.

There are limited markets for C&D products, which is partially due to the perception that recycled building products are of inferior quality to virgin products, despite research proving that recycled products are at least equal or greater in quality than virgin products. Construction specifications often do not recognise recycled aggregate. Specifications outlined in contracts can arguably be met by recycled aggregate however contractors are reluctant to incorporate recycled material into their operations due to a fear of the material not meeting contractual requirements (Cardno BSD 2007). The Town of Kwinana and Waste Stream Management carried the first project involving Local Government use of recycled concrete aggregate (RCA) since 2000. Waste Stream Management provided the Town of Kwinana with 1,500 tonnes of free material to build a test road in the Hope Valley area, which Council engineers and Main Roads WA (MRWA) will monitor in collaboration for a number of years. The road and the road-base currently meet MRWA standards (Cardno BSD 2006). Based on test results carried out by MRWA City of Canning amended their road-base tender documents to include recycled materials. The local authority road project (year 2008) for widening 780 metres of Welshpool Road required 1,800 m^3 of sub-base, which was provided by C&D Recycling (WMAA 2008).

1.1.7. Cement Kiln Dust and Lime Kiln Dust

Cement Kiln Dust (CKD) and Lime Kiln Dust (LKD) are fine by-products of Portland cement and lime from high-temperature rotary kiln production operations that are captured in the air pollution control dust collection system (e.g., cyclones, electrostatic precipitators, and baghouses).

CKD is the fine-grained, solid, highly alkaline waste removed from cement kiln exhaust gas by air pollution control devices. Because much of the CKD is actually unreacted raw materials, large amounts of it can be, and are, recycled back into the production process. Some CKD is reused directly, while some requires treatment prior to reuse. CKD not returned to the production process is typically disposed in land-based disposal units (i.e., landfills, waste piles, or surface impoundments), although some is also sold for beneficial reuse (USEPA n.d.).

LKD is physically similar to cement kiln dust, but chemically quite different. LKD can vary chemically depending on whether high-calcium lime (chemical lime, hydrated lime, quicklime) or dolomitic lime is being manufactured.

1.1.7.1. Qualitative/quantitative information

Cockburn Cement currently produces approximately 15,000 tpa of CKD, and nearly all is disposed to landfill. It is unlikely that the company will be able to eliminate the production of CKD, however they may be able to reduce the production of CKD following commissioning of new electrostatic precipitator.

Cockburn Cement produces more than 50,000 tpa of LKD. Some is sold, while the rest is currently stockpiled on-site. Cockburn Cement aims to reduce LKD being landfilled down to zero, and only produces LKD to meet customer demand. Cockburn Cement has developed a process to return this material to the kiln to convert it to product. Trials to date have shown success in returning 30% of production. Current markets for the material include acidic stack gas scrubbing, road stabilisation, and soil treatment.

1.1.7.2. Potential uses (FHWA 1998)

- Asphalt Concrete Mineral Filler

CKD and LKD have been used as mineral filler in asphalt concrete mixes. The blending of CKD into the asphalt cement binder prior to incorporation with the hot mix aggregate results in a binder (mastic) that can significantly reduce asphalt cement requirements (between 15 and 25 percent by volume). Further, the lime components of the CKD and LKD can assist in promoting stripping resistance (preventing moisture-related damage resulting from the separation of the asphalt cement film from the aggregate at its interface in the presence of moisture that is most common in siliceous aggregates). In this application, these dusts can be used to replace hydrated lime or liquid antistripping agents.

- Asphalt Concrete Aggregate

CKD and LKD can also be agglomerated or pelletized to produce an artificial aggregate for special applications. In Japan an oil-absorbing artificial aggregate is reportedly manufactured using CKD . This is used to improve the rutting resistance of asphalt concrete pavements by absorbing the lighter fractions of excess asphalt cement binder during hot weather.

- Asphalt Cement Modifier

CKD can be added to asphalt binder to produce a low ductile mastic asphalt. Mastic asphalt is a mixture of asphalt binder and fine mineral material. When mastic asphalt is produced using CKD mixed 50/50 with an asphalt cement binder, a potential exists for a relatively large volume replacement of asphalt cement (between 15 and 25 percent by volume). The European use of mastic asphalts, with low ductility, for bridge deck waterproofing and protection is well documented, and this could represent a potential application for kiln dusts elsewhere.

- Stabilised Base or Flowable Fill Cementitious Materials

CKD can be used as a cementitious material or a pozzolan activator in stabilised base or flowable fill applications. LKD has the potential for use as a pozzolan activator in each respective application. As a cementitious material, CKD can replace, or be used in combination with, Portland cement. As a pozzolan activator, both CKD and LKD can replace or be used in combination with Portland cement or hydrated lime.

1.1.8. Red lime

1.1.8.1. Qualitative/quantitative information

Red lime is the residual product from the process of conversion of sodium carbonate to sodium hydroxide in the Bayer process. It is a combination of calcium carbonate, mono carbonate and tri-calcium aluminate. This residual lime is added to the bauxite residue stream as a means of disposal. It is estimated that the red lime contributes around 5% of the total residue mass, or 100 Kt tonnes annually, generated in the Kwinana refinery (Cooling 2007).

1.1.8.2. Potential uses

The primary use opportunity for red lime is to increase the pH of soils, either alone or in combination with other soil amendment agents. It could also be used for neutralisation of acidic effluents or waste streams.

1.1.9. Red sand

1.1.9.1. Qualitative/quantitative information

In Western Australia, Darling Range bauxite deposits contain high levels of quartz. As a result, during the extraction of alumina from bauxite ore a coarser residue fraction is being produced, called red sand. The red sand is generated in the

Kwinana refinery in similar quantities to the typical bauxite residues, red mud, at approximately 2 Mt per annum.

1.1.9.2. Potential uses

As red sand is a unique by-product specific only to Western Australian bauxite, not much information for its potential uses can be found in the literature. Generally the red sand can be used everywhere natural sand could be used, and any of the potential uses discussed in section 1.1.5 are applicable for the red sand. Some particular applications are considered in detail within the next chapter.

Alcoa supports a diversity of research initiatives into potentially beneficial uses of its residue. Some potential uses that have been identified and continue to be investigated include:

- Use as fill for earthworks for commercial and residential developments (alone or mixed with other materials);
- Use as fill for roadworks;
- Use a substitute for road base material;
- Use a s flowable fill aggregate;
- Use as concrete aggregate;
- Use as a component in soil amendment mix to help retain nutrients and adjust soil pH;
- Use as a filtration medium to remove phosphorous and nitrogen from sewage treatment in domestic and industrial septic systems;
- Use as an additive to compost to aid the retention of trace metals;
- Use in brick and tile manufacture;
- Use as road base, either using the sand fraction directly, or the mud as a component of a composite (for example with gypsum or fly ash); and
- Use as raw materials for the production of cement alternatives, such as mineral polymers and ceramics.

1.2. Potential local demand

Many of the inorganic residues generated within the KIA could be utilised as alternative, or supplemental, sources to meet the growing demand for construction materials, providing they meet specific environmental criteria and technical specifications. The 3B3 project has identified a number of imminent and planned infrastructure, residential and commercial development projects within a reasonable distance from KIA (approximately 20 km) to assure economic viability for the use of these by-products. Estimation (where information is available) for the volumes of construction and fill materials needed to carry out these projects is provided in the summary below.

1.2.1. James Point Port Stage 1, Kwinana

The project (EPA WA 2004) (D.A. Lord & Ass 2001) proposes the construction of cargo wharves and associated cargo handling facilities to the north of James Point, Cockburn Sound in Western Australia. The planned completion is expected to be within five years post approvals. At present it is not clear when the construction will begin, as there is no announced date for commencing the works.

The port development will comprise:

- Construction of an offshore breakwater approximately 850 m long;
- Dredging of 1.2 million m^3;
- A total of 1.375 million m^3 of reclamation to create 1,200 m of berth face and 19 ha of hardstand wharf;
- Berth face construction using sheet piling or piled concrete deck;
- Wharf paving; and
- Services, crane rails, fendering and bollards, etc.

The estimated materials needed to carry out this project are presented in the table below:

Imported clean sand fill	137,000 m^3 The dredge material will be used to fill the land-backed berth and additional clean fill will be obtained from sources of known quality, most probably from Baldivis;
Seawalls, core	938,000 m^3 imported construction materials (not specified)
Seawalls, armour	235,000 m^3 imported materials
Offshore breakwater:	>500,000 m^3 The breakwater will consist of limestone core armoured with limestone boulders. The limestone will be sourced from existing quarries in Hope valley.

The estimated transport of rock armour, core material and fill will require approximately 56,000 truck movements over a period of 9 months.

1.2.2. Kwinana Quay Project (formerly Fremantle Outer Harbour)

Originally four port facility options were strategically assessed against environmental, social and economic factors, and after a long stakeholder consultation process one of them was recommended. However in July 2007 the Cabinet (of the Western Australian Government) approved the proposed Fremantle Ports' new overflow container facilities – the Kwinana Quay project, to proceed to the next stage of Environmental Protection Authority (EPA) assessment and statutory planning approval. Cabinet resolved that two proposed options are to proceed to this stage, and on completion of this process , subject to approval, only one of the these two options will be selected for construction, being either (GHD 2007):

- an island design about one kilometre offshore and linked by an open spanned bridge to an extension of Rowley Road, north of the Alcoa refinery (referred to as the *Offshore Island Option*); or
- a partially land-backed facility located just south of Alcoa that would include reclamation of the foreshore and an island component with a freight link via Anketell Road (referred to as the *Landbacked Option*).

These two proposed options are smaller than either one of the original four options, but nevertheless still requiring millions of tonnes of construction materials, approximate volumes summarised in the table below (adapted from (GHD 2007)):

	Offshore Island Option	**Land-backed Option**
Stage 1 Development		
Breakwaters and seawalls	1,200,000 m^3 imported rock fill 600,000 m^3 imported rock armour	1,000,000 m^3 imported rock fill 600,000 m^3 imported rock armour
Reclamation	From dredged material only	4,200,000 m^3 imported fill
Stage 2 Development		
Breakwaters and seawalls	Nil	300,000 m^3 imported rock fill 100,000 m^3 imported rock armour
Reclamation	Reclamation volume of 7,000,000 m^3 will be obtained from dredged materials and imported fill	7,000,000 m^3 imported fill

For the original four options the Strategic Assessment carried out by GHD in 2006 (GHD 2006) has established that the annual availability for limestone and sand within the area represents 20-25% of the requirements for each of the options. In the Draft Kwinana Quay Scoping Document (GHD 2007) major consideration is given to the investigation of the use of recyclable and recycled materials. If these are not identified then the potential impacts of the creation or the expansion of existing quarries will be taken into consideration.

1.2.3. Keralup (formerly Amarillo)

Keralup is a 4000 ha property in government ownership in the south-west corridor, lying 10 km to the north-east of Mandurah with 3,000 ha of development area. It will host a population of about 60,000. The first lots of land are planned for release in 2011 with life of the development phase being over 20 to 30 years. In the original Environmental Review (EPA WA 1997) the need for Imported clean fill was estimated to be approximately 5,500,000 m^3 , however in the latest masterplan (Taylor Burrell Barnett 2007), published in September 2007 the very preliminary estimates indicate that there is sufficient fill material within the Keralup site. According to a news article in The West (9 June 2007) having to deal with acid sulphate soils is expected, which may increase the originally predicted volumes of clean fill. The final volumes of imported clean fill will be addressed at the detailed planning and design stages, and additionally site preparations near Serpentine River will require further detailed site investigations as appropriate.

The need for road construction materials is estimated to be approximately 500,000 $m^{3,}$ and this amount is grossly underestimated.

1.2.4. Wungong Urban Water Redevelopment Scheme

In 2004 the State Government expanded the Armadale Redevelopment Authority's jurisdiction to include approximately 1500 ha of Brookdale to facilitate its viable redevelopment as a high quality urban area encompassing world best practice in sustainability. The ARA envisages that the redevelopment project will set in place planning guidelines and a management framework to enable residential development to house up to 40,000 people over the next 15 years.

Located adjacent to the Armadale Strategic Centre at the edge of Perth's South East Corridor, the Amendment area is bounded by Armadale Road, Eighth Road, Ninth Road, Rowley Road, Hopkinson Road and the Tonkin Highway

The low-lying nature of the Brookdale area presents a number of challenges to achieving a commercially viable development. In order to comply with the DEC's Average Annual Maximum Groundwater Level (AAMGL) policy, which requires that the AAMGL be maintained and fill imported to give adequate separation between the land surface and the groundwater. Approximately 7,500,000 m3 of fill will be required. Importing this volume of fill would significantly impact on the project feasibility and as a result, alternative approaches are being examined (ATA Environmental 2006).

1.2.4.1. Latitude 32 (Hope Valley Wattleup) *(LandCorp 2004)*

The redevelopment area comprises approximately 1426 ha and is located inland of the Kwinana to Henderson coastal industrial area. The land in that area was identified for industrial expansion within 14 indented precincts with which new development and land use must comply. The project is expected to be developed over a 25-30 year period. At this stage it is unknown how much imported fill and materials will be required. This information will be available when the earthworks model and subdivision plans are developed. It is anticipated that the extraction of basic raw materials will be permitted in some of the precincts, which will necessitate developers to seek importing clean fill into the area.

A summary of the quantities of the main construction materials needed for infrastructure within 20 km of the KIA, and the possible inorganic by-products in the KIA that could supply this demand are shown in Figure 1.

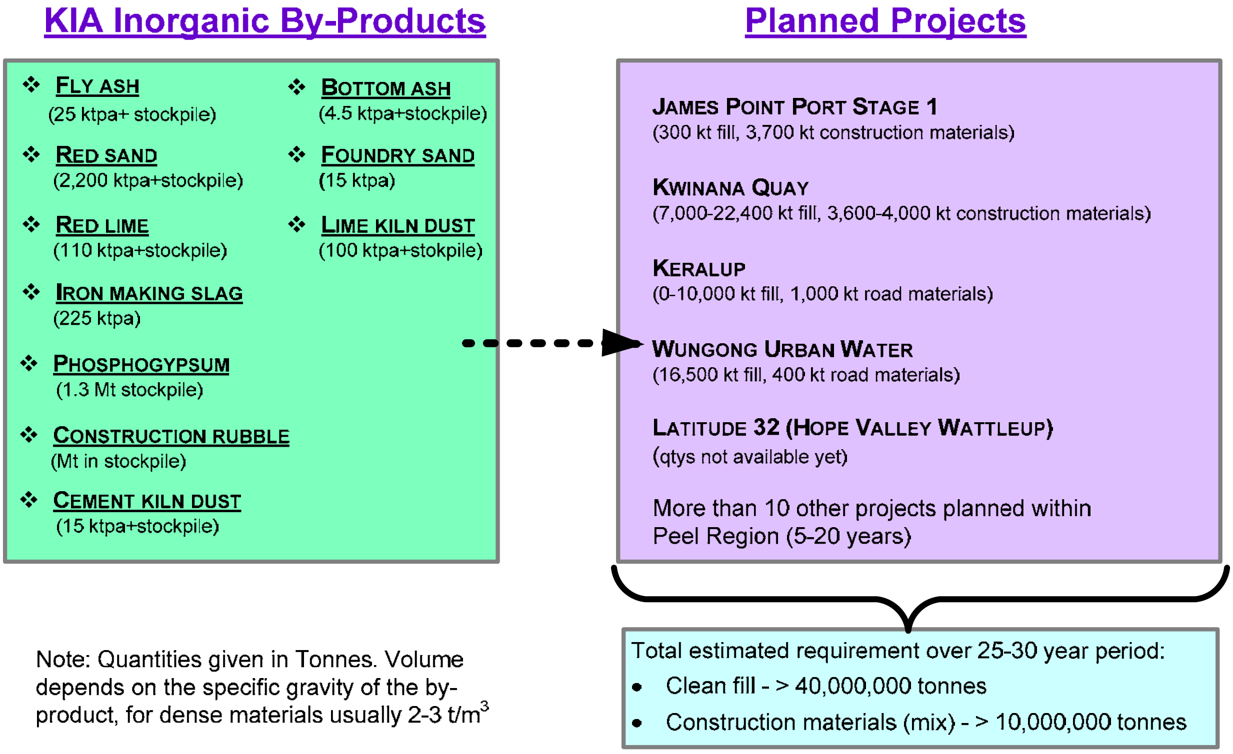
1.2.5. Other projects

A large number of planned infrastructure projects were identified, largely in the Peel region (Anon 2006) with expected timeframes varying between 5 and 20 years. These are expected to compete with the projects described above, thus continuing to contribute to the increase demand for basic raw materials. These include, but are not limited to:

- Tonkin Hwy extension to Mundijong Road
- Pinjarra Bypass
- Mandurah Estuary Bridge duplication
- Regional and recreation centre
- Waroona Bypass
- Old Mandurah traffic bridge replacement

- Technology park
- Short haul Airport
- Houseboat Port – Peel inlet
- Floating island/resort

The future projects outlined above will result in serious pressure on the supply of basic raw materials that need to be utilised within the Kwinana region in the next 20-25 years. The cumulative amount estimated so far amounts to millions of tonnes of imported fill and construction materials (see Figure 1). As stated before it has already been identified that the current supply is insufficient to meed this demand. Table 1 outlines the potential of various inorganic residues generated within the area that could be considered for supplementing the demand on natural materials.



KIA Inorganic By-Products

- **FLY ASH** (25 ktpa+ stockpile)
- **BOTTOM ASH** (4.5 ktpa+stockpile)
- **RED SAND** (2,200 ktpa+stockpile)
- **FOUNDRY SAND** (15 ktpa)
- **RED LIME** (110 ktpa+stockpile)
- **LIME KILN DUST** (100 ktpa+stokpile)
- **IRON MAKING SLAG** (225 ktpa)
- **PHOSPHOGYPSUM** (1.3 Mt stockpile)
- **CONSTRUCTION RUBBLE** (Mt in stockpile)
- **CEMENT KILN DUST** (15 ktpa+stockpile)

Planned Projects

JAMES POINT PORT STAGE 1
(300 kt fill, 3,700 kt construction materials)

KWINANA QUAY
(7,000-22,400 kt fill, 3,600-4,000 kt construction materials)

KERALUP
(0-10,000 kt fill, 1,000 kt road materials)

WUNGONG URBAN WATER
(16,500 kt fill, 400 kt road materials)

LATITUDE 32 (HOPE VALLEY WATTLEUP)
(qtys not available yet)

More than 10 other projects planned within Peel Region (5-20 years)

Total estimated requirement over 25-30 year period:

- Clean fill - > 40,000,000 tonnes
- Construction materials (mix) - > 10,000,000 tonnes

Note: Quantities given in Tonnes. Volume depends on the specific gravity of the by-product, for dense materials usually 2-3 t/m^3

Figure 1: Local demand (within 20 km) for construction materials and potential inorganic residue supply options in the KIA.

Table 1 Potential uses for KIA generated inorganic residues

	Fly ash	**Bottom ash**	**Slag**	**PG**	**Foundry sand**	**C&D**	**CKD**	**LKD**	**Red Lime**	**Red sand**
Fill	■	■	■		▨	■				■
Roadbase aggregate	░	■	■			■	░	░		░
Fine aggregate for concrete		■	■		▨					░
Coarse aggregate for concrete		■	■		▨	■				
Flowable fill	■	■			▨		■			■
Cementitious material	■									
Agriculture	░			░					░	░
Cement substitute (geopolymer)	░		░				░	░		

Legend:

■	Used as is or with minor beneficiation (may require some physical processing, such as crushing or washing)
░	Mixed with other by-products
▨	Requires processing before use

2. ECONOMIC ASSESSMENT

This section features a high level economic assessment for red sand utilisation for a selected number of uses. This specific material was chosen because of the extensive work being carried out by Alcoa for that by-product, thereby enabling access to more accurate data required for the analysis.

This assessment does not take into account any future changes in sand quarrying practices and locations as well as any future government or other intervention that might influence the market for fill material or fine aggregates.

2.1. Technical Considerations

This assessment focuses on the following key uses for red sand:

1. Fill for earthworks for commercial and residential developments;
2. Fill for roadworks;
3. Road base material; and
4. Concrete aggregate.

2.1.1. Physical properties of red sand

Typical red sand consists of quartz (reported as about 56% SiO2), iron oxides (reported as about 20% hematite & 5% goethite) and alumina (reported as 10% Al2O3). The density of red sand ranges between 1600 and 1800 kg/m3 while the specific gravity of red sand is typically 2.94. The surface area of red sand is in the area of 5.38 m2/g.

Microscopy of red sand indicates it consists of discrete particles of quartz and of iron oxides. Particles have been shown to have a high angular nature allowing the sand to have strong mechanical properties with a California Bearing Ratio (CBR) of around 50%. This CBR is significantly higher than typical sands found on the Western Australian Coastal Plain which have values between 12% and 18%.

With minimal processing, red sand will fit the “construction fill” particle size gradient and it is also likely to be suitable for road embankment construction, including sub-grades and foundations (Jamieson et al. 2006).

2.1.2. Environmental Constraints

The environmental concerns about the use of any alternative material are based on the potential for certain constituents to leach into the soil and groundwater at concentrations that are hazardous to the environment and human health. The use of red sand needs to be assesses in terms of its potential environmental consequences in comparison to the virgin material it replaces.

In WA, assessment of leachability is measured using the Australian Standard Leaching Procedure, based on the USEPA Toxicity Characteristic Leaching Procedure. The method is designed to assess the leaching of materials intended for co-disposal to landfill and is not perfect for assessment of material intended for other applications. The Energy Research Centre of the Netherlands (ECN) has developed a pH dependence leach test for characterising the leaching behaviour of materials.

The test is currently used by the European Union countries. The method provides a broader overview of the leaching information, over a wider pH range, for different environmental conditions.

Leach testing of red sand has been completed and the results compared against relevant criteria from the Department of Environment and Conservation waste guidelines, the European Union waste guidelines and the Dutch Building Materials Decree. The results have also been compared to the leaching behaviour of some typical soils. The results to date indicate that the red sand should not present any environmental risk (Attiwell 2007).

2.1.3. Engineering Constraints

Even if the economic assessment is favourable some physical properties of the material and specific technical requirements established by national standards or particular agencies may limit the use of any inorganic residue. Similarly to other construction materials the feasibility of using red sand as an alternative material is dependent on the set of properties outlined in these standards and/or guidelines.

Due to the different physical properties of the red sand compared to typical sands on the Coastal Plain extensive research efforts have been carried out to demonstrate its potential for replacing natural materials. The list below outlines the applicable standards and specifications relevant to each use application:

2.1.3.1. Fill for earthworks for commercial and residential developments

The Department of Environment and Conservation's Clean fill Definition (DEC 2005) is in line with the AS 3798: 1996, Guidelines on earthworks for commercial and residential developments.

The Definition reads: "Material that will have no harmful effects on the environment and which consists of rocks or soil arising from the excavation of undisturbed material. For material not from a clean excavation, it must be validated to have contaminants below relevant ecological investigation levels (as defined in the document Assessment Levels for Soil, Sediment and Water, Department of Environment, 2003)".

2.1.3.2. Fill for roadworks - Main Roads WA Specification 302 Earthworks

Laboratory test have been conducted to establish red sand's suitability for roadwork's applications. It has been concluded that red sand satisfies the Main Roads specifications for fill, subgrade and drainage (Cooling et al. 2004).

2.1.3.3. Road base material

The use of red sand was investigated as a substitute for road base material in Western Australia (Jitsangiam et al. 2007). A soil stabilisation technique was used to improve the properties of red sand to satisfy Main Roads specifications for road bases. A pozzolanic-stabilised mixture comprising Class F fly ash and lime kiln dust was used to develop pozzolanic activity. It was concluded that the performance of the stabilised red sand satisfies the required standards and exhibits a higher resilient modulus and better permanent deformation characteristics in comparison with the commonly used material for road base (crushed rock with 2% General Purpose cement).

2.1.3.4. Concrete aggregate

The use of red sand as fine aggregate in concrete manufacture has been investigated, as well as the use of fly ash as a cement replacement (A Shri wahyuni et al. 2006). The particle size distribution for red sand falls within the limits of the particle size distribution curves given in the Australian Standard AS 2758.1:1998, Aggregates and Rock for Engineering Purposes. The results show that the concrete strength is not scientifically affected when natural sand is substituted with red sand. Issues found with high water permeability and high chloride levels continue to be investigated.

2.2. Economic Considerations

Financial considerations may play a significant role when deciding to use red sand as a substitute to a virgin material. The decision whether or not to use an alternative material, assuming that it complies with technical specification, would in most cases depend on the variance in cost between the virgin sand and the red sand for different applications.

There are a number of costs that need to be considered when evaluating the use of alternative materials, including:

1. price of the material defined by the company generator (it may contain some or all processing costs as well as the capital costs);
2. cost of the processing (may include operational, labour and equipment costs);
3. cost of any additional equipment needed when using this material;
4. cost of additional material/s needed to bring the quality of the alternative material to the required standard (dependent on application);
5. cost of transportation;
6. cost of stockpiling; and
7. cost of handling.

In this economic analysis the cost of the natural materials is assessed, since the exact cost of the red sand in not known, until a commercial size processing plant is in place. Major consideration has to be given to the fact that the local supply of natural sand is declining which is already pushing up the price and cost of transportation (Jerrard 2007a) (Jerrard 2007b) for the virgin material. It is likely that the final cost of the red sand will be lower than natural sand, which will make it not only a competitive, but also a preferred material for developments requiring large amounts of fill and building materials. In addition to this the use of red sand will have a number of sustainability benefits compared to using the virgin material.

For the purposes of simplicity the cost of stockpiling and handling are considered to be the same for the natural sand, the red sand and any other additional materials required. In fact, these costs would differ only marginally, as the materials have similar physical properties.

Three options are assessed in the following discussion:

1. Sand as fill material;
2. Sand as fine aggregate in concrete versus red sand and fly ash; and

3. Road base material (crushed rock + 2% General purpose Portland cement) versus stabilised red sand (red sand + fly ash + lime kiln dust)

Prices quoted below are estimates and are obtained from the Rawlinson Australian Construction Handbook, (Rawlinson 2006) unless stated otherwise. All prices taken from Rawlingson (2006) are multiplied by an escalation factor of 1.2 to represent the current prices.

2.2.1. Sand as fill material

A search of locally available quarries was carried out and their list and location are presented in Table 2 and graphically in Figure 2.

Table 2 List of sand quarries in Perth Metropolitan Area

Operator	Location	Material
Rocla	Armadale Road, Banjup	Concrete sand
	Creighton Road, Gingin	Quartz sand for high strength concrete
	Gnangara Road, Landsdale	Bricklaying, plastering, filling sands
	Gaskell Avenue, Lexia	Concrete, filling, high grade sand
	Sixty Eight Road, Baldivis	Bricklaying, plastering and concrete sands
Readymix	Armadale Road, Jandakot	Sand
	Stock Road, Mandurah	Sand

The distances between Alcoa's residue area, the closest sand quarries and the planned projects outlined in Section 1.2 are shown in Table 3.

Distances are obtained from the distance tool in GoogleEarth (Google n.d.) and represent the approximate distance in a straight line. Since most of the prices obtained are for delivered material (inclusive of the haulage) the distances in this case do not matter as much. However the data in the table below can be used to assess the saving that can be made if a cheaper material, located at a closer site is chosen. Estimated transport costs are \$0.20-0.25 per tonne per kilometre (or \$0.46-0.57 per m^3).

Table 3 Distances to planned projects for clean sand fill

	Alcoa residue area	**Closest sand quarry**		**Second closest sand quarry**	
Latitude 32	2.5 km	9.3 km	Readymix, Jandakot	42.7 km	Rocla, Lexia
James Point Port	5 km	15 km	Readymix, Jandakot	47.5 km	Rocla, Lexia
Kwinana Quay	5 km	15 km	Readymix, Jandakot	47.5 km	Rocla, Lexia
Keralup	24 km	5.8 km	ReadyMix, Stock Road	70 km	Rocla, Lexia
Wungong	18.3 km	13.4 km	Readymix, Jandakot	43.1 km	Rocla, Lexia

NOTE: Readymix quarries appear in both applications – filling and concrete sand as there is no specification on their website what material they produce.

The price of the clean sand fill for the metropolitan area is \$15-20 per m^3 delivered. The price of imported fill (mixed sand and heavy aggregate) is estimated at \$40-50 per m^3, delivered.

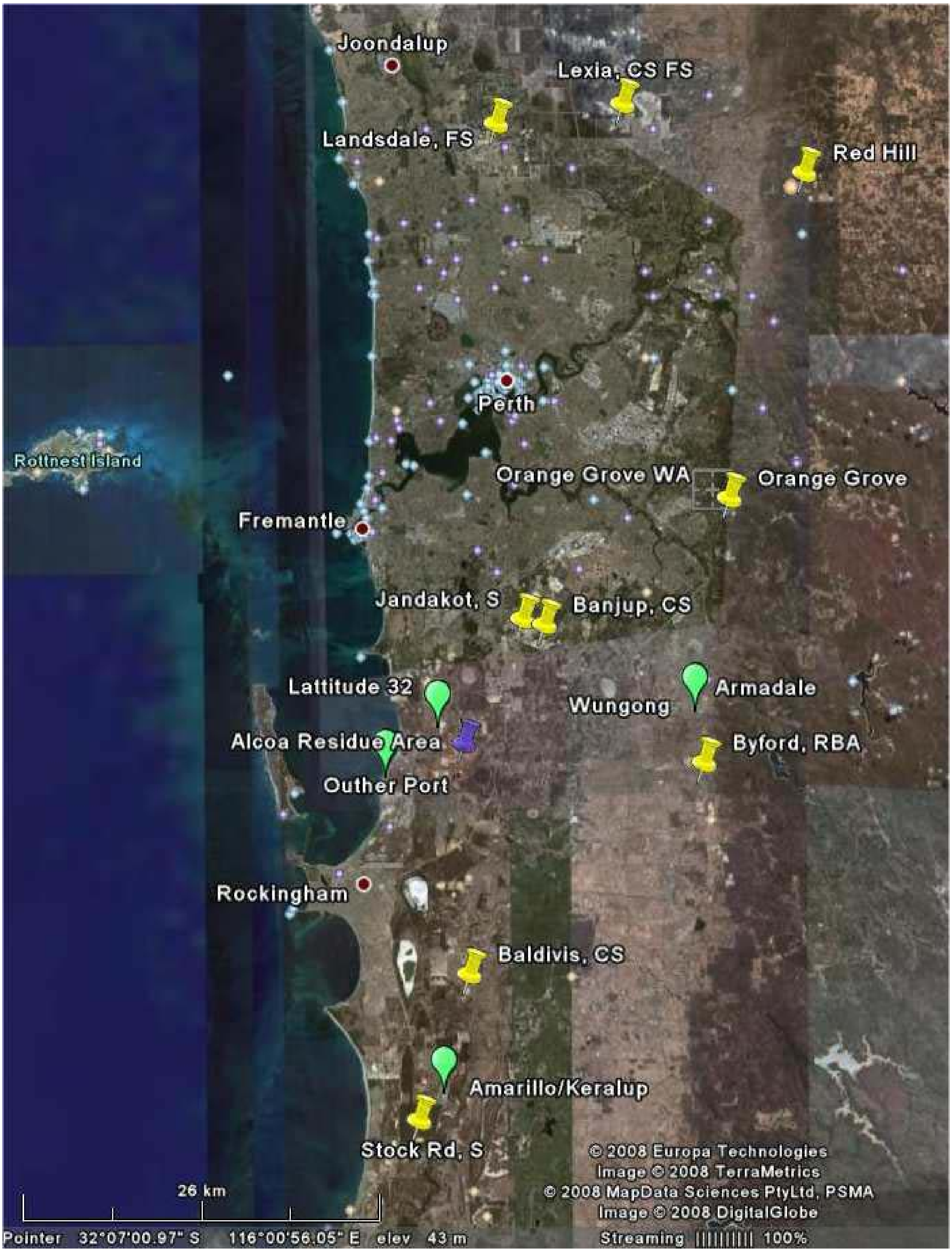


Figure 2 Location of sand and aggregate quarries in Perth Metropolitan Area (Source GoogleEarth)

2.2.2. *Sand as fine aggregate in concrete*

The potential for utilisation of red sand as concrete sand is limited to only James Point port and Kwinana Quay. The distances between Alcoa's residue area, the closest sand quarries and the planned projects are shown in Table 4.

Table 4 Distances to planned projects for concrete sand

	Alcoa residue area	**Closest sand quarry**		**Second closest sand quarry**	
James Point Port	5 km	15 km	Rocla, Banjup or Readymix, Jandakot	17.1 km	Rocla, Baldivis
Kwinana Quay	5 km	15 km	Rocla, Banjup or Readymix, Jandakot	17.1 km	Rocla, Baldivis

NOTE: Readymix quarries appear in both applications – filling and concrete sand as there is no specification on their website what material they produce.

2.2.3. *Road base material (crushed rock + 2% General purpose Portland cement)*

Table 5 shows the quarries in the Perth Metropolitan Area producing roadbase aggregate.

Operator	**Location**	**Material**
Hanson	Red Hill	Aggregates, Road base
	Byford	Aggregates, Road base
Boral	Orange Grove	Aggregates, Road base

Table 5 List of roadbase aggregate quarries in Perth Metropolitan Area

Operator	**Location**	**Material**
Hanson	Red Hill	Aggregates, Road base
	Byford	Aggregates, Road base
Boral	Orange Grove	Aggregates, Road base

The distance between Alcoa's residue area and Hanson's Red Hill quarry is approximately 50 km (north), while the distance to Boral's Orange Grove is approx 27 km (north-east). Hanson's Byford quarry is located at a competitive distance for road projects around and south of Kwinana.

The price for cement stabilised base is estimated at $100-130 per m^3, delivered. Hanson's prices for roadbase aggregate are $16.50 -17.20 per tonne (approx $38-40 per m^3), excluding GST and delivery (Hanson n.d.).

2.3. Sustainability Considerations

2.3.1. *Environmental Benefits*

- Reduction of land disposal - the use of red sand will reduce or even eliminate the development of residue stockpiles.

- Conservation of virgin sand - the supply of virgin sand in close proximity to Perth is becoming limited, which enhances the case for the use of red sand as an environmentally friendly and economically viable solution.
- Reduction of land clearing.
- Reduction in GHG emissions associated with crushing (for aggregate) and transport.

2.3.2. Economic Benefits

- Reduction in transport distance - the close proximity of the bauxite residue stockpile will reduce the need to transport natural sand from longer distances.
- Reduction of disposal costs and associated liabilities - the use of red sand will offer savings from handling and stockpiling as well as extending the available life of existing landfills.
- Overall project savings - there may be considerable project savings by using a lower amount of virgin sand. This saving is increased by the reduction of transportation and disposal costs.
- Minimising impacts to existing roads with reduced transportation: Using the red sand close to it source eliminates the need to import large volumes of virgin material.

2.3.3. Social Benefits

- Reduction of unsightly stockpiles.
- Reduction of emissions (including GHGs) and particulates due to reduced transportation.
- Health and safety benefits associated with the reduced volume being stockpiled.

There are other economic, environmental and social benefits to the use of red sand and these would be captured in a more rigorous life cycle sustainability assessment of red sand and the virgin sand material.

All of the above technical, economic and sustainability considerations lead to the spontaneous conclusion that the red sand is a product that has acceptable technical characteristics, and provides a wide range of sustainability benefits when used as a replacement for virgin sand in infrastructure projects. red sand is expected to be economically competitive as well, and its convenient location to some of the upcoming major civil engineering projects makes it a valuable material. Prices for natural materials and associated transport are only expected to increase in the future, leading to an increased attraction regarding the use of inorganic by-products, assisting with focussing end-user’s attention on alternative materials.

3. WAY FORWARD

Based on the work done in this paper, and the regulatory frameworks paper, a way forward has been developed for enabling the use of inorganic by-products from the KIA in surrounding infrastructure projects. This way forward has the following components:

- Analysis of the physical and environmental (i.e. leachability) properties of the inorganic by-products and the requirements to enable them to meet the existing standards, or requirement, for use in infrastructure projects.
- Development and testing of suitable beneficiation methods to enable the by-products to be processed on a large scale to meet the requirements of the end use.
- Development of regulatory frameworks and Standards to enable the re-use of inorganic by-products as common practice (not by exception on a case by case basis).
- Undertake lifecycle sustainability assessments comparing inorganic by-products with the use of virgin materials. This includes development of case studies for the different materials.
- Trialing and testing of inorganic by-products in small scale applications prior to use in large scale applications.

This paper recommends that the CSRP and KIC proactively, and quickly, commence work with the Western Australian Government to develop the relevant regulatory framework and standards to enable the reuse of inorganic by-products in infrastructure projects. Using the range of existing regulatory frameworks and standards that already exist in other countries these could be developed relatively quickly for Western Australia, or Australia as a whole. This includes a standard, similar to the European EN 12920, for characterisation of waste.

Concurrently with this, CSRP and the KIC should undertake research to develop the required beneficiation methods and equipment to prepare the materials to the required standard and specifications. A number of trial, or demonstration projects should be undertaken, in conjunction with the relevant Government agency, using the materials in a range of infrastructure applications.

Research should also be undertaken to assess the life-cycle sustainability benefits (or otherwise) of reusing inorganic by-products compared to using virgin conventional materials. This could produce a number of case studies that could inform Government and the community about the sustainability benefits of using these materials.

This program would form the basis of the 3B3 extension.

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