Lynas Advanced Materials Project: Preliminary Comparison of Residue Disposal Options

WorleyParsons
resources & energy

Lynas MALAYSIA SDN. BHD.

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Lynas Advanced Materials Project

Preliminary Comparison of Residue Disposal Options

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SYNOPSIS

Lynas Malaysia Sdn Bhd (Lynas) is currently undertaking the detailed design for an Advanced Materials Plant based on hydrometallurgical processing of lanthanide concentrate material in Malaysia to be built in the Gebeng Industrial Estate (GIE), Kuantan State. WorleyParsons were requested by Lynas to undertake an assessment of alternative options for the disposal of the various process residues. Three separate residue streams are produced; Flue Gas Desulphurisation residue (FGD); Neutralisation Underflow residue (NUF); and Water Leach Purification residue (WLP). Each of these are examined in this report.

Exploring alternative residue disposal options is consistent with a policy of sustainable process design. WorleyParsons have, in preparing this report, focussed on mechanisms to avoid, wherever possible, the production of waste streams with potential environmental impacts. In their place we have explored by-product sale, conversion and re-use with long term storage in the Residue Storage Facility (RSF) only considered as a last resort.

Our work has shown that the residues have potential value as nutrient sources for the palm-oil industry in Malaysia. This could have foreign exchange implications since almost all palm oil nutrients are currently imported. Also potentially viable is the sale into the building and construction markets. A final selection of the most effective option requires further appraisal of CAPEX and OPEX expenditures in Malaysia, which has not been possible without some further selection of likely candidate projects. A detailed analysis of these is beyond the scope of this preliminary report.

PROJECT 4219298-300-EN-RP- 105-0 LYNAS ADVANCED MATERIALS PROJECT

REV	DESCRIPTION	ORIG	REVIEW	WORLEY-PARSONS APPROVAL	DATE	CLIENT APPROVAL	DATE
A	IDC (Not Issued)	E Leitch	BD Hill	N/A		N/A	
B	IFR (Not issued)	E Leitch	BD Hill	N/A		N/A	N/A
0	Approved for Design	K Bapatla	BD Hill	N/A	17-Jan-08		N/A

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1. INTRODUCTION

1.1 Project Background

WorleyParsons were requested by Lynas Malaysia Sdn Bhd (Lynas) to undertake an assessment of alternative options for the disposal of a range of residues arising from the processing of lanthanide concentrate in their Advanced Materials Plant to be built in the Gebeng Industrial Estate (GIE), Kuantan State, Malaysia. Lynas is currently undertaking the detailed design for the plant.

Lanthanide concentrate will be transferred to the Advanced Materials Plant where it is subjected to the cracking and separation process involving concentrated acid in a rotary kiln and water leaching of the calcine. Following three stages of leaching and solid-liquid separation, solvent extraction will be used to separate, purify and concentrate the lanthanide elements. The lanthanide elements are finally precipitated and calcined to produce a range of carbonate and oxide products.

As a result of the lanthanide concentrate processing, three separate residue streams are produced; Flue Gas Desulphurisation residue (FGD); Neutralisation Underflow residue (NUF); and Water Leach Purification residue (WLP).

The three residue streams (FGD, NUF, and WLP) are subjected to pressure filtration and assumed to be in paste form (moisture contents between 30% and 40%), once processed.

1.2 Sustainable Process Design

The alternative residue disposal options examined in this report are consistent with a policy of sustainable process design. WorleyParsons have, in preparing this report, focussed on mechanisms to avoid, wherever possible, the production of waste streams with potential environmental impacts. In their place we have explored by-product sale, conversion and re-use with long term storage in the Residue Storage Facility (RSF) only considered as a last resort.

At a technical level, due to variations in slurry and dried densities as well as rheological factors, markets for the various residue streams are not obvious at first examination, since in most cases the residues consist of pastes with no apparent value. Hence the report also discusses physical and chemical processes which could be used to add value to the residue streams, with particular emphasis on Malaysian conditions.

1.3 Requirement for Residue Storage

In recognising that many of the residues currently have limited perceived value, it was agreed that this may change in the future with improvements in technology and new and emerging markets.

Hence, Lynas is keen to see some of these by-products stored in a manner which would enable processing at a future date. For this reason, WorleyParsons developed a reliable containment strategy in a RSF which is included in a separate design report (4219298-300-EN-RP-101).

1.4 Terms and Definitions

For the purpose of this report, 'dewatered' residue refers to residues with a solids-liquid ratio in excess of 60 w/w% solids (i.e. less than 40% water). Alternative descriptions include thickened paste, filter cake and dry residue disposal. Generally, residues or tailings with a water content of less than 50% are described as 'thickened', with water less than 40% as paste and less than 30% as cake or 'dry'. Perceptibly, the performance of any particular tailings or process residue is determined by a range of factors in addition to the water content, so that these terms are generally only to be used as an indication of likely behaviour at different water contents. Additional factors influencing actual slurry behaviour includes dominant particle sizes and shapes, mineral composition, size distribution, temperature, pressure and particle interactions which are a feature of the particular minerals within the residue. The study of the relationship between moisture content, these other factors, and the physical characteristics and behaviour of a waste (residue) product is referred to as rheology.

1.5 Regulatory Framework

In Malaysia, matters pertaining to the management of radioactive substances come under the jurisdiction of the Atomic Energy Licensing Board (AELB). Applicable legislation includes the Atomic Energy Licensing Act, 1984 and its subsidiary regulations, namely the Radiation Protection (Licensing) Regulation, 1986. As the lanthanide concentrate (raw material) and the three residue streams by-products exhibit a low level of radiation, these materials are classified as 'radioactive substances' under the Atomic Energy Licensing Act, 1984. Therefore the operation of the plant requires a Class A Milling License from the AELB in accordance with the requirements of the Act.

In order to obtain the approval of the AELB, we understand that Lynas will need to design a suitable RSF which is sound from the engineering, environmental and radiological perspectives. The onus will be upon the proponent to ensure that with the final design selected, the environmental risks (pertaining to soil and groundwater) are low and the radiation exposure to the nearby communities is within the prescribed limits of 0.3 mSv/yr (imposed by the AELB). The design of the RSF shall be developed in conjunction with the AELB, the Malaysian Nuclear Agency (MNA) and the Department of Environment (DOE). The MNA will conduct a Radiological Impact Assessment (RIA) of the various radioactive residue management options for submission to the AELB.

This report is conceptual in nature and further investigations should be conducted at either laboratory or pilot scale to identify the technical viability of some of the identified options. This should ideally be followed by a preliminary *cost-benefit* analysis to rank the likely treatment costs and recoverable revenue streams. The investigation and analysis may identify at least one intractable waste stream where onsite disposal within secure, engineered cells may be considered for permanent storage. This option will be assessed in the RIA prepared for the plant.

2. ADVANCED MATERIALS PROJECT - PROCESS DESCRIPTION

2.1 Lanthanide Ore Concentration

The Lynas Advanced Material Plant processes lanthanide concentrate at an integrated processing site utilizing physical and chemical treatment processes. The lanthanide concentrate is first to be prepared in Australia by a *physical* beneficiation operation employing mineral flotation. This process takes crushed ore containing 17-20% lanthanide ore and produces a lanthanide concentrate containing typically 40% lanthanides and waste materials which will remain in Australia.

2.2 Cracking and Separation Process

The subsequent Cracking and Separation, involves predominantly *chemical* processes employing hot sulphuric acid digestion and a number of advanced hydrometallurgical and solvent extraction (SX) processes. The process flow sheet is presented in Figure 1 (attached) and the processes within the operation are introduced in more detail below.

The initial processing rate will be the processing of 32,680 tpa lanthanide concentrate which following unloading from ship is transferred to the cracking separation plant for processing.

Within this plant, the lanthanide concentrate is treated with sulphuric acid at a moderately high temperature to decompose the more refractory lanthanide containing minerals. The resulting residue is then agitated with water and the resulting process liquor is treated via a series of process steps to remove various impurities. Following this, the liquor is mixed with a number of specialised reagents and then submitted to a solvent extraction process to recover a number of high quality product streams. Although complex, this is nevertheless a mature process technology and widely used in China to recover lanthanide products, albeit from different raw material sources. During the various process steps, additional materials are introduced to the process streams to enable recovery of the product or neutralisation of off-gas streams for environmental or emissions requirements.

The principal waste product streams comprise:

- Water Leach Purification (WLP) residues resulting from the leaching and purification of the water soluble lanthanide components from the calcined, cracked concentrate;
- Waste Gas Treatment residues – referred to in this report as Flue Gas Desulphurisation (FGD) residues; and
- Neutralisation Underflow Solids (NUF) consisting principally of the reaction product of an acidic sulphuric acid derived liquor with calcium, magnesium and aluminium based minerals to produce calcium, magnesium and aluminium sulphates.

These residue streams are summarised in Table 1.

Table 1: Residue Streams Summary

Residue Stream	Expected Disposal Condition	Supernatant Water and Surface Water Runoff	Lining Required if stored on-site	Potential Residue End Uses
FGD	Paste	Captured and contained in storage pond and returned to waste water treatment facility.	Dual Liner System (HDPE/low permeability clay)	Sale
NUF	Paste	Captured and contained in storage pond and returned to waste water treatment facility.	Dual Liner System (HDPE/low permeability clay)	Sale
WLP	Paste	Captured and contained in storage pond and recycled into cracking and separation process stream.	Dual Liner System (HDPE/low permeability clay)	Storage or sale

2.3 Quantity of Waste Generated

The anticipated annual dry mass and volume of residue per annum over a 10 year project lifespan generated by the lanthanide extraction process for the three streams is summarised in Table 2.

Table 2: Average Quantities of Residue Generated

Residue Stream	Annual Dry Mass Year 1 (tpa)	Assumed Dry Density (t/m^3)	Annual Volume Year 1 to Year 2 (m^3)	Annual Volume Year 3 to Year 10 (m^3)	10 Year Volume (m^3)
FGD	27,900	1.05	26,600	53,200	478,800
NUF	85,300	1.05	81,300	162,600	1,463,400
WLP	32,000	0.70	45,800	91,600	824,400
Total	**145,200**		**153,700**	**307,400**	**2,766,600**

3. WASTE MANAGEMENT STRATEGY/PHILOSOPHY

An alternative approach to the disposal of the process residues was early recognised by Lynas. This approach was to identify potentially beneficial uses for some (or all) of the process wastes and residues. This approach regards residues and other materials generated by the project as by-products rather than 'wastes'. In order to identify possible uses and markets, a 'brain-storming' workshop was conducted. The workshop included Lynas management as well as WorleyParsons process engineers, environmental scientists and civil and geotechnical engineers. The results of the workshop were documented and then distilled into those with some reasonable potential for success. These candidate projects are detailed below.

3.1 Advantages of By-Product and Re-use Approach

There are numerous examples demonstrating that this approach can have beneficial impacts during the life of a project. Some of the key benefits include:

- potential for cash flow generated by sale or disposal of by-products;
- minimisation of impacts and potential impacts arising from long term storage of wastes;
- minimisation of construction costs and other site works related to stored materials such as lined cells, impervious capping, groundwater monitoring wells and interception and diversion channels; and
- reduction or elimination of ongoing monitoring costs and risks to regulatory agencies, which are often an expensive and long-term component of waste storage, particularly where emotive and complex technical issues such as the half-life of radioactive materials and the decay chains of other complex lanthanide materials are concerned.

3.2 Disadvantages of By-Product Approach

The main disadvantages of this approach are that for more complex materials it often requires additional time and investment at commencement to identify potential markets for by-product streams and to provide facilities to prepare the residues for commercial sale or further use. This requirement comes at a time when many projects are focussed on short term project financing needs.

In addition, many benefits may have little, if any, current commercial value, which, however, may change in the future. These changes could arise due to improvements in process technologies (e.g. residue re-processing for gold and tin), developments of markets for previously un-costed externalities (e.g. carbon trading) or demands brought about by changing societal values (e.g. paper, glass or plastic recycling).

These various factors were given consideration and developed via the residue management / ‘brainstorming’ workshop into the Residue Management Strategy below.

3.3 Applying the Residue Management Strategy

Applying a by-product sale or re-use hierarchy approach to the various residue streams of the project provided the following results.

The FGD stream, consisting predominantly of gypsum (manufactured calcium sulphate) could find useful sales in the Malaysian plasterboard market, although the product would need to compete with both virgin gypsum and a range of other (similar) by-product or manufactured gypsum sites. Other markets include the cement industry for manufacture of blended cements and agricultural markets as a calcium and sulphur nutrient and for the treatment of saline or otherwise impervious clay soils.

The NUF residues carry high levels of magnesium, aluminium and calcium sulphate. In particular, magnesium sulphate present as the mineral Kaiserite is beneficially used throughout the acid soils of the humid tropics, the dominant soil type in Malaysia, at rates of up to 100 kg/hectare as a palm oil nutrient (Product brochure, Kali & Stauff Corporation, undated). This is because magnesium and potassium are considered more critical to nutrition than the traditional fertilizer components nitrogen and phosphorus (“Preferred Fertilizer Materials for Acid Soils of the Upland Humid Tropics", Food and Agriculture Organisation (FAO) of the United Nations, 1987). Although the content of aluminium is considered less desirable than the magnesium content desired by FAO, the calcium sulphate is also considered to complement the materials value since it acts as a source of both calcium and sulphur for these soils (ibid).

The WLP residues also contain relatively high levels of the nutrients phosphorus and magnesium which have potential agricultural markets. Phosphorus is widely recognised as a rate limiting nutrient in soils throughout the world, including Australia, Europe and America. However, as it competes with fertilizers carrying from 8% to 21% by weight of phosphorus, it was conceded that proximate markets would be essential to product marketability.

Following on this initial brainstorming session, further investigations were carried out to provide additional information on which to base an informed residue management decision. These further investigations and the results derived are detailed below.

4. RESIDUE MANAGEMENT OPTIONS

The options for managing the various process residue streams are discussed below. Generally it was agreed that the options available for residue treatment could be grouped into a number of broad groups:

These groups are:

- wet storage / disposal;
- dry treatment and stockpiling for sale; or
- combination / other.

These options are discussed below.

4.1 Wet Storage/Disposal

4.1.1 Conventional Slurry Disposal (45-55w/w%)

This is the conventional, proven technology generally suitable for most residue disposal and tailings options – particularly in arid climates. However, it was agreed that it may be unsuitable for the Malaysian climate. The high rainfall in the Gebeng area (c > 3m year) and low evaporation (c < 1m year) suggests that residues disposed as a wet slurry will not readily densify. The high phreatic surface resulting from this presents a serious risk of critical tailings failure / overflow. If this were to become the preferred option it would require detailed geotechnical design and seismic hazard evaluation.

Photo 1: Lisheen Wet Tailings Facility, Ireland.

4.1.2 Paste Disposal of Residue (70-72w/w%) (Fluor/HGE/Centrifuge Vendors)

With sustainable water use/reuse becoming an increasing component of any resource development, particularly in more arid climates, this option is being considered by a number of current and future mineral processing sites. The high rainfall at the Lynas site in Malaysia, however, may present similar difficulties to those of the wet residue, though with a much lessened liquefaction potential. It would require detailed rheological data on the content of the residue to evaluate their stability and drying characteristics.

The slurry or paste is generally deposited in the centre of the disposal site to form a conical pile, typically generating slope angles of 3 to 10 degrees, providing the underlying material has stabilised. As the layers of paste cease to flow, desiccation can occur producing cracks. The new overlaying flow fills in the cracks and locks the layers together, forming a more stable structure.

Surface paste disposal evolved from technology used for underground backfilling of voids. As a consequence, dewatering technology has been driven by the demand to produce lower water content residue which have seen the development of high rate and deep cone thickeners that often have height to diameter ratios of greater than unity. Additives such as flocculants and coagulants are usually added to the residue feed or the thickener to dewater the residue to higher densities. The types of additives used reflect how the paste behaves when pumped and how the residue will flow once at the storage facility.

Photo 2: Myra Falls Paste Tailings Disposal, Canada.

4.2 Dry Residue Options

As an essential first step, it is generally necessary to cost-effectively dry the residue. To avoid wasteful energy use, it was agreed that the process of drying could be facilitated by the following chemical (hydration) and mechanical (pelleting/agglomerating/ filtering) processes.

- Solidification through additive hydration.
- Solidification through mechanical pressing.
- Solidification through agglomeration.
- Solidification through encapsulation or drumming.
- Solidification - encapsulation by in situ piling (Dolomatrix/other licensees).
- Belt or drum filters - with dry stockpiling or disposal.
- Other solidification processes (filters/geotubes)

These options are discussed below.

4.2.1 Stabilisation/Solidification by Additive Hydration

This option relies on the ability of either relatively high cost cement or a range of low cost waste materials, such as cement kiln and fly ash dust, to densify slurries and process residues to enable either beneficial uses for the resulting product or permanent containment for intractable wastes. Essentially this is a chemical reaction (hydration) between a cementing or pozzolanic agent and the excess water found in the process residues, although physical forces can play a part where the resulting cement slurry is contained within a formwork system during the hydration process There are several commercial organisations providing services utilizing industrial wastes for a range of useful end uses. The Cement and Concrete Association of Australia has devoted considerable effort to the development of solidification technologies utilizing Ordinary Portland Cement (OPC). Similarly, a recent US publication, *A Critical Review of Stabilization/Solidification Technology* by Jesse R. Conner A1 and Steve L. Hoeffner is available from WMX Technologies, Inc., West, 1950 S. Batavia Ave., Geneva, Illinois 60134 or by download from the publisher for modest cost. In addition, a recent report for EPA Victoria addressed the effectiveness of OPC solidification technology for the treatment of intractable wastes. The report can be downloaded from: www.epa.vic.gov.au/waste/docs/Meinhardt_Stage1_Report.pdf.

4.2.2 Solidification Through Mechanical Pressing

This approach relies on the ability of certain moisture containing materials to be extruded and shaped into pellets or similar agglomerated particles. The use of mechanical pressure enables some moisture to be eliminated or for partial drying to occur, one or both of which has the effect of producing a granular or pelleted residual material. Once in this form, the residue would be significantly easier to manage, using conventional materials handling equipment (conveyors, elevators, loaders, trucks). The process can be aided by including components that exert a hydrating reaction, such as cement, fly ash or quick lime.

4.2.3 Solidification Through Physical Agglomeration

Although similar to mechanical pelleting, this process generally relies on achieving an increase in residue density by imparting a rolling action on the particles, usually facilitated by introducing a starting granule or 'seed' upon which successive layers of damp material are built. There are two main types of agglomerating machines, disk and drum, both of which rotate and cause granules to form and grow progressively as they roll on a moving bed of damp residue feed. To avoid accumulation in the disk or drum surface, the surface is cleaned by either scrapers or the use of a flexible liner. The flexible liner in a drum granulator cleans itself at top-dead-centre when the liner reverses itself to discard accumulated residue. Agglomeration using this method has significantly lower energy requirements per tonne of throughputs than mechanical pressing or extruding. The major disadvantage is that an additional process step (i.e. screening) is generally required to achieve a uniform granule size. This can be eliminated in an efficient disk granulator with an attendant reduction in throughput as a result of the lower surface (rolling) area.

4.2.4 Solidification Through Encapsulation/Drumming

The comparatively low radioactivity of the various process residues potentially makes this option unnecessarily costly given the possible market potential of some of the other alternatives. The ultimate activity of the residues would determine if this is a viable option. It may also present problems with the long term storage and associated liabilities following plant closure.

Photo 3: Drum Disposal.

4.2.5 Waste Encapsulation - HDPE (Argonne/Other Licensees)

This technology has approval from the US EPA for storage of medium radioactive level waste. Cost would likely present a significant obstacle as it would require the sourcing of polyethylene, itself a product of increasing market value.

A recent market study by Kapline Enterprises, Inc. for the Department of Energy in the US thoroughly identified and rated potential applications and markets for depleted uranium metal and other low level radioactive oxide materials such as thorium. The technology for treatment of low level radioactive lanthanide ore materials by polyethylene encapsulation have been proven to effectively and efficiently process similar powder and granular materials. In addition, the process is very flexible. Polyethylene products can be heated and reworked if future needs change. Further recovery of the low levels of residual lanthanide oxide materials could potentially also be retrieved from the encapsulated product as a resource in the future, if needed. Ideally, recycled plastics from industrial or post-consumer sources can be used in place of virgin materials to reduce cost and improve viability. Brookhaven National Laboratory has extensively developed, tested and demonstrated polyethylene encapsulation processes for low-level radioactive, hazardous, and mixed wastes. During processing, waste materials are mechanically mixed into the molten polyethylene binder, producing a workable homogeneous product. The process is not susceptible to chemical interactions between the waste and binder, enabling a wide range of acceptable waste types, high waste loadings, and technically simple processing under heterogeneous waste conditions.

The process has evolved from proof-of-principle, through bench-scale development and testing, to full-scale technology demonstration and technology transfer.

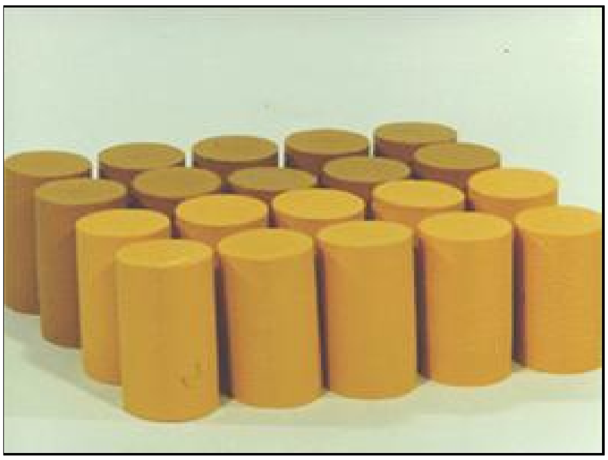

Photo 4: Polyethylene Encapsulation.

4.2.6 Waste Encapsulation - in situ Piling (Dolomatrix/Other Licensees)

Pending a licensing agreement between Dolomatrix or a similar company, this process could present a practical solution to the disposal of low level radioactive residues. It would also have the advantage of value adding to the site prior to plant closure by removing the need for further site compaction.

The Dolocrete Technology is a world wide patented catalyst and binder system based on uniquely calcined dolomitic minerals. According to the company web-site, the combination of specifically chosen materials in the Dolocrete system enables waste to be chemically bonded within a stable and inert matrix. The system yields results comfortably passing maximum allowable world standards and has been rigorously tested by accredited independent laboratories and universities. WorleyParsons has not verified this information for accuracy or application to the Lynas WLP residues but has experienced the products efficacy in dealing with *red mud*, a by-product of the alumina refining industry.

The company claims using the technology at a commercial scale to treat thousands of tonnes of site remediation soils, dredging sediments, mining wastes and industrial process residues. It is currently the favoured method of toxic waste disposal for the New South Wales (Australia) EPA. Dolomatrix currently operates under license in the Philippines and it is possible that a license could be granted to Lynas for use of the technology in Malaysia.

Photo 5: Dolomatrix Concrete in situ Piling.

Photo 6: Agglomerated Fill and Cement.

4.2.7 Belt Filters and Dry Residue Disposal

Belt and drum filters provide a conventional mechanism to separate solids from a residue slurry; however, they are generally only suited to high value commodities rather than low value by-products. The main reason for this is the high operating cost – frequently involving both vacuum pumps and fabric filters, both of which have high maintenance and energy requirements. They are included here for completeness, although they are unlikely to be as cost effective as other alternatives presented here, particularly the Geotube option considered at the end of this section.

Photo 7: Typical Belt Press Showing Dry Filter Cake Development.

Further discussion below details the handling mechanisms available for stockpiling or disposal of dried residue once produced, either by agglomeration or filtering as previously discussed.

4.3 Dry Residue Disposal (Granulated Product/Mechanically Extruded Pellets)

The success of this option will ultimately be determined by the final radioactivity of the blended residue. A 50/50 mix of WLP residues with other products, including other by-products, may produce a marketable product. Palm oil fertilizer is a potential choice given the dominance of palm oil agriculture throughout eastern and western Malaysia and the high phosphorus content of the residue. By blending or co-extruding with gypsum and dolomite powder or with the NUF residues, sulphur, calcium and magnesium nutrient requirements of palm oil plantations could be met. Preliminary investigations of the potential uptake of uranium and thorium oxides into plant material, as well as the approval of the relevant Malaysian authorities, would be required (see Regulatory Framework above).

Currently, a number of systems are available to produce blended pellets, which would be required, including the following.

- Hydraulic piston presses operate in a similar manner to standard mechanical piston presses. The benefit of hydraulic presses versus a mechanical press is that the machine can be engineered very light and compact. Presses of this nature are common in the production of biomass products, such as briquettes. Some modification to the die and associated working parts may be necessary to compensate for the more abrasive nature of the residue.

- The alternative to a hydraulic press, with its associated problems with compaction/density, is the use of a conical screw press. BMD in Belgium currently manufactures such plants for use in compacted biomass products. The output can be as bricks or, ideally in this case, pellets.

The die through which the pellets are extruded can also be heated by way of an electric resistance heater wrapped around the die. Heating of the die can greatly reduce the moisture content of the final product and aid in material handling. See *Table 3* for pelletizing machinery manufacturers.

Table 3: Pelletizing Machinery Manufacturers

Machinery Type	Manufacturer	Country of Manufacture	Capacity	Notes
Conical screw press	BMD Europe	Belgium	600-100 kg/in	
Screw extruders without die heating	Kusters Venlo-Holland	Holland	300 kg/in	used for chicken manure
Screw extruders without die heating	Sai Kampangsaen	Thailand	4 ton/day or 500 kg/in	used for decayed bagasse - relatively small
Screw extruders with die heating	Shimanda	Japan	400-800 kg/in.	
Screw extruders with die heating	PINI+KAY	Japan	400-800 kg/in.	
Screw extruders with die heating	Komarek	various, including China	various	http://w a/index.html

Photo 8: Pelletized Product (as a potential source of revenue from suitable process residues).

4.3.1 Dry Residue Disposal (Fines)

This disposal option reduces the seismic risk for the long term storage of wet process residues. The greatest disadvantage, however, is the much higher energy cost associated with dewatering and then partially drying the residue / tailings. Dewatering conventional tailings to higher degrees than paste produces a filtered wet (saturated) and dry (unsaturated) cake that can no longer be transported by pipeline due to its low moisture content. These filtered tailings are normally transported by conveyor or truck, deposited, spread and compacted to form an unsaturated tailings deposit. This type of residue storage produces a stable deposit requiring little or limited retention bunding and is referred to as 'dry stack'. It has significantly lower environmental impact; however the potential for dust must be considered, particularly during the dry season. The chemical characteristics of the residues would also determine to some extent, the final moisture content of the waste.

Photo 9: Dry Stack Tailings, La Copia, Chile.

4.3.2 Other Filter Based Solidification Processes ('Geotubes')

The use of the GeoTube in situ filter technology appears to be an alternative/substitute for a pressure filtration system within the process plant for some of the residues, particularly the WLP residues. The GeoTube option removes one of the material handling steps but adds significantly to residue disposal costs since they cannot be re-used. The potential to source lower-cost filter tube technology from China provides an opportunity for this technology to be cost-effective for residue disposal.

Assuming that the GeoTubes will be placed and filled at the RSF, a pumping and piping system will be required that would replace the use of a front-end loader and truck transporting material from the processing plant to the drying shed and from the drying shed to the RSF.

DESIGN CONSIDERATIONS

Decant water leaking from the external face of the GeoTubes is expected to be collected and contained in a lined and bunded channel system and returned (pumped) to a Waste Water Treatment Facility (WWTF). This will also include rainfall runoff falling over the GeoTube area.

The GeoTubes will be placed in a bunded and lined (HDPE or PVC) facility. The embankments may be lower compared to a conventional design. The GeoTubes would be placed on a filter medium (sand or gravel) to facilitate the flow of water beneath the tubes. The use of underdrainage piping, to facilitate drying of the GeoTubes, should also be considered. Earthworks to prepare foundation soils would be required for the GeoTube system (filling, compacting, filter layer construction, bunds/ embankments).

The main disadvantage of this technology is that the area of land set-aside for GeoTube filling contains non-load bearing materials, with a high moisture content. It is likely that any such reclaimed areas may only be suitable for parkland/gardens applications but not for industrial infill development.

- The use of flocculants and coagulants may be required for the dewatering to work effectively and maximise solids content of the WLP residue within the tubes. Problems experienced with the pilot plant filtering may be relevant to the success of using GeoTubes. Specifically, the effectiveness of the coagulant to bind residue solids and enhance dewatering.
- It will be important to understand time requirements for dewatering of a GeoTube after filling with slurry before refilling can occur. The GeoTubes are filled with slurry, allowed to dewater, and then refilled with slurry until the tube is full of dewatered solids. It will be essential that sufficient GeoTubes are available for filling while other GeoTubes are in the process of dewatering.
- The ability to optimise stored residue volumes may depend on efficiency of GeoTube fillings subsequent to the initial tube filling and requires investigation (i.e. if slurry on second filling can be expected to penetrate full length of GeoTube).

Compaction of the residue mass will not be possible using the GeoTube system. Thus, final stored residue volumes and densities will depend on the dewatering efficiency of the GeoTube system and consolidation of the residue due to pressure applied from overlying GeoTubes.

Photo 10: Geotubes (note one Geotube in the process of dewatering)

5. SAFETY AND ENVIRONMENTAL CONSIDERATIONS

5.1.1 Wet (Slurry) Disposal in Conventional RSF

A recent global analysis of critical failures of conventional tailings storage facilities demonstrates that in many cases they can be linked to a high phreatic surface beneath the dam wall, usually caused by surplus liquor or raised water-tables. These conditions are exacerbated in seismically active areas.

It would therefore be prudent in the design of a purpose built RSF for slurry or paste disposal to examine its behaviour in a range of modelled scenarios, such as during a 1 in 100 year rainfall event and during a period of relatively high seismic activity. Wherever possible, dam embankment walls should be designed on the centre-line raise method to a geotechnical stability factor-of-safety of 1.5 (ANCOLD Guidelines) to avoid the potential for over-turning. It is customary for such storage facilities to be modelled geotechnically to determine the factor-of-safety (FOS) for a number of seismic and static scenarios. This should be undertaken in the event that an RSF solution is chosen for the facility.

5.1.2 Drum Filtered (Semi-dry) Residues to RSF

The geotechnical stability is considerably greater using partially-dried residue and as a result, the proposed RSF would have significantly reduced safety, environmental and/or stability issues.

The storage of dry residues would need management of dust during disposal to avoid mobilising low level radionuclides in some of the residue materials.

5.1.3 Cement Stabilisation/Localised Drumming and Disposal

This option results in any waste materials being mixed with a stabilising cement material and placed into drums which are subsequently disposed either off-site or on-site. On-site disposal offers the greatest control over the ultimate burial and containment of the material and hence is potentially the safer option. Depending on ultimate end use or destination, off-site disposal has the potential for the use or disposal of the material to fall outside Lynas' control. Off-site disposal to a recognised landfill or for other industrial site development uses would be an acceptable end-use, particularly if the landfill is licensed to accept weakly radioactive waste materials. However this option precludes materials being subsequently reclaimed for sale and is likely to be a more costly option than others considered.

5.1.4 In situ Piling for Industrial Site Development

This potentially offers the highest level of safety for the options considered since the material is unlikely to be re-located or excavated and re-sold. Although additional tests needs to be undertaken to verify the compatibility of identified residue streams with different cement substrates, we believe that it offers the lowest safety risk of the various options considered. Further lab scale studies are warranted.

5.1.5 Pelleted and Commercial Use

Lynas would need to convince regulatory agencies that no long term liability was likely to arise as a result of the slight residual radioactivity of the uranium and thorium. One way to achieve this is to control the manufacture of by-products at the plant to achieve an activity of less than 30Bq/gm in order to meet international standards. The pelleting process for mixed wastes, supplemented if necessary by other nutrients, provides an excellent means of ensuring this. In addition, testing should occur to evaluate the uptake (if any) of thorium and lanthanide compounds into plants, with an emphasis on palm oil, but perhaps also investigating plants for human consumption which are commercially or domestically grown in the region.

5.1.6 Others

There are numerous other possible configurations, particularly since the by-products and waste products from the operation may ultimately be blended together to produce a range of products for various proximate agricultural markets. It is beyond the scope of this preliminary report to investigate these various options.

6. POST CLOSURE SITE DEVELOPMENT OPTIONS

The table below discusses post closure development options for the site. The options are based on available information on current site conditions.

Table 4: Post Closure Site Development Options

Land Use Option	Suitability/Applicability	Constraints	Information/Data Required
1. Residential	• Not very compatible with the existing land use of the surrounding area i.e. industrial and agricultural	• Site must be sufficiently compacted and stable enough for construction of residential properties. • Radiation levels from the residue must be within the approved limits for residential usage from a recognised agency, either local or international. • Land use classification of the site might need to be changed. Current land use classification is industrial. As the immediate surrounding land use is either industrial or agricultural, this change might prove to be problematic. • Land use option might not be compatible with the surrounding properties. • Final ground level must be high enough to ensure that the area will not be flood-prone. • Relatively high construction cost.	• Radiation data including acceptable levels for human exposure. • Geotechnical report after final capping/site closure which should include groundwater level and flow information. • Detailed costs.

Land Use Option	Suitability/Applicability	Constraints	Information/Data Required
2. Agricultural - oil palm - coconut palm - rubber	• Compatible with the surrounding land use, especially oil palm as there	• Soil cap must be of the type that is suitable for the chosen plant species. • Soil cap must be of effective soil depth for the cultivation of chosen plant species. • Should the site appear to be water logged, a sufficient drainage system must be implemented for species that are sensitive to water (e.g. oil	• Radiation data including acceptable levels for agricultural use. • Uptake study on

Land Use Option	Suitability/Applicability	Constraints	Information/Data Required
- other fruit crop	are existing oil palm plantations in surrounding areas. • Change of land use classification might not be an issue as some of the surrounding land use is currently agricultural.	palm). • Soil cover must be of sufficient strength to uphold the chosen plant species. • For some plant species, soil might need to be renourished with appropriate fertilizers. • Land use classification of site might need to be changed. Current land use classification is industrial. • Low to moderate economic value for most compatible agricultural species.	radionuclides from residue to plants. • Geotechnical report after final capping/site closure which should include groundwater level and flow information. • Soil screening study of residue and soil cap to determine soil suitability to the plant species chosen. • Detailed costs.
3. Industrial	• Compatible with the surrounding land use. • Might not require	• Site must be sufficiently compacted and stable enough for construction of an industrial facility. • Radiation levels from the residue must be within the approved limits for industrial usage from a recognised agency, either local or international.	• Radiation data including acceptable levels for human exposure.

Land Use Option	Suitability/Applicability	Constraints	Information/Data Required
	reclassification for land use. • High economic value	• Final ground level must be high enough to ensure that the area will not be flood-prone. • Relatively high construction cost.	• Geotechnical report after final capping/site closure which should include groundwater level and flow information. • Detailed costs.
4. Green Lung/Park/ Recreation	• Might not require reclassification of land use. • Community friendly option.	• Land use option might not be fulfilling the criteria of pre-determined land use of the area. • This land use option does not have any further economic value other than the cost of the land should it be sold back to the state government for green lung/ park development; however, for this land use option, the expected economic value will be low. • Unsuitable location; might not be required in area.	• Detailed costs.

Land Use Option	Suitability/Applicability	Constraints	Information/Data Required
5. Commercial - small businesses/ shop lots	• Low to moderately high economic value, depending on other commercial centres in area.	• Site must be sufficiently compacted and stable enough for construction of commercial buildings. • Radiation levels from the residue must be within the approved limits for commercial land usage from a recognised agency, either local or international. • Final ground level must be high enough to ensure that the area will not be flood-prone. • Land use classification of site might need to be changed. Current land use classification is industrial. • This land use option might not be economically viable. • Relatively high construction cost.	• Radiation data including acceptable levels for human exposure. • Geotechnical report after final capping/closure which should include groundwater level and flow information. • Might require an economic viability study to ensure it is a suitable option. • Detailed costs.

Land Use Option	Suitability/Applicability	Constraints	Information/Data Required
- car park	• Might not require reclassification of land use. • Modest construction cost.	• Site must be sufficiently compacted and stable enough for construction and use as a car park. • Final ground level must be high enough to ensure that the area will not be flood-prone. • The land use option might not be economically viable or required.	• Geotechnical report after final capping/closure which should include groundwater level and flow information. • Might require an economic viability study.

7. SUMMARY AND CONCLUSIONS

This study concludes that alternative disposal strategies to a conventional slurry based RSF could ultimately be more cost effective as well as presenting better health, safety and environmental (HSE) outcomes. A number of potentially viable options requiring further consideration were identified.

In particular, it is believed that the Lynas process residues have potential value as nutrient sources for the palm-oil industry in Malaysia. This could have foreign exchange implications since almost all palm oil nutrients are currently imported. Further work at determining the modifications required to residue streams to achieve the required nutrient status and physical characteristics for marketing and use are warranted.

The FGD stream, consisting predominantly of gypsum (manufactured calcium sulphate) could find useful sales in the Malaysian plasterboard market, although the product would need to compete with both virgin gypsum and a range of other (similar) by-product or manufactured gypsum sites. Other markets include the cement industry for manufacture of blended cements. There is potential also for sale into Malaysian and other proximate agricultural markets as a calcium and sulphur nutrient.

A final selection of the most suitable option requires further appraisal of CAPEX and OPEX expenditures in Malaysia, which has not been possible without the further selection of likely candidate projects. This report summarises the most likely disposal options and provides meaningful data in order to carry out additional research and a cost-benefit analysis of the various options. Such an analysis is an essential next step but is beyond the scope of this preliminary report.

8. INFORMATION ON INTERPRETATION, USE AND LIABILITY OF THIS REPORT

This report has been prepared in accordance with a specific brief and scope of work. It should be read in its entirety.

The responsibility of WorleyParsons is solely to Lynas Malaysia Sdn Bhd. This report is not intended for, and should not be relied upon, by any third party. No liability is undertaken to any third party.

Any interpretation or recommendation given in this report shall be understood to be based on judgement and experience, not on greater knowledge of facts other than those reported.

If changed or significantly different residue chemical, physical or rheological characteristics occur subsequent to the production of actual process materials, WorleyParsons should be notified of the differences and provided with an opportunity to review the recommendations contained in this report.