A REVIEW OF RARE EARTHS PROCESSING IN MALAYSIA

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ABSTRACT

In Malaysia, there were two rare earths processing plants namely Asian Rare Earth (ARE) and the Malaysian Rare Earth Corporation Plant (MAREC) in Perak, which were operated until 1992 and were subsequently closed due to problems pertaining to disposal of large amount of radioactive waste. Recently, Lynas Advanced Materials Plant (LAMP) has become one of the largest rare earths processing plant in the world producing rare earth elements (REE) in Gebeng, Pahang. The primary raw material is lanthanide concentrate (LC) which is imported from Mount Weld mine in Australia and shipped to Malaysia. LC is produced from lanthanide ore after mining and mineral processing. The ore has a lower impact than Bayan Obo, Mountain Pass and adsorbed clay deposits, given the small footprint of the mine itself and the remoteness of the location. The type of ore being mined (rare earth phosphates: carbonatite, monazite) may have higher thorium content than bastnasite ore from the Chinese or American mines but still far below radiation concerns. This paper was written to review the processing flowsheet at the Lynas Advanced Materials Plant (LAMP), the environmental impact associated with the processing of the said ores and the sustainability of the operation.

KEYWORDS: Lynas, rare earth elements, sustainable processing, sustainable development

1. INTRODUCTION

Rare earth elements (REE) refer to the 15 lanthanides which include lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu). Yttrium (Y) and scandium (Sc) are sometimes considered REE due to their similar chemical properties, and because they are often found in the same ore deposits. In spite of their importance, rare earth minerals rarely exist in economically viable concentrations and they are usually hard to extract. REEs possess wide nuclear, chemical, optical, electrical, metallurgical, and magnetic properties. Examples of the applications include catalysts in petroleum refining industry, as alloying agent in metallurgical processes, in glass, phosphors, optics, permanent magnets, and electronics. Emerging and potential applications include using rare earths to absorb ultraviolet light in automotive glass, corrosion protection, and metal coatings in corrosive and salty environments (Koltun and Tharumarajah, 2014). The elements are typically divided into two sub-groups: the cerium sub-group of ‘‘Light’’ rare earth elements (LREEs) which includes La to Eu and the yttrium sub-group of ‘‘Heavy’’ rare earth elements (HREEs) which include the remaining lanthanide elements, Gd to Lu, including yttrium (Gupta and Krishnamurthy, 1992; Jordens et al., 2013; Trifonov, 1963). However, Scandium, when it is classified as a rare earth element, is not included in either the LREE or HREE classifications (Gupta and Krishnamurthy, 1992; Jordens et al, 2013). Half of the world’s 110 million tons of reserves exist in China while other sizable deposits are found in Russia, United States, Brazil, India, Australia, Canada, and Greenland. The countries known to be actively mining REE are China, Russia, India, Brazil and Malaysia (Hao et al., 2015). Among these countries, China has the largest REE production, accounting for more than 93% of global supply (Yap, 2015). The critical metal report (Moss et al. 2011) listed 14 economically vital raw materials that are prone to supply disruption and concluded that supply disruption would threaten the goal for cleaner transport and sustainable energy since rare earth metals are used in products using green technology, such as hybrid/electric vehicles, carbon capture systems, wind power generation, low-energy lighting, and energy efficient flat-screen displays.

The history of rare earth processing in Malaysia goes back to two companies: the Asian Rare Earth (ARE) and the Malaysian Rare Earth Corporation Plant (MAREC) in Perak, which had been operated until 1992 and closed due to several reasons such as environmental problems and disposal of vast amount radioactive wastes (Omar 2010; Meor Yusoff and Latifah, 2002; ASM, 2013, 2011; Al-Areqi et al., 2014a). Recently, Lynas

Advanced Materials Plant (LAMP) in Gebeng, Pahang, has become one of the largest rare earths processing plant in the world producing rare earth elements. The plant processes lanthanide concentrate (LC) which is imported from Mount Weld mine in Australia and shipped to Malaysia. LC is produced from lanthanide ore after mining and mineral processing. The plant utilizes physical and chemical treatment processes for REE productions. The LAMP is located close to the Kuantan deep-water port, adjacent to the Balok River. Kuantan and its metropolitan area, which is located at the edge of the South China Sea, has a population of more than half a million (Figure 1). Currently, over 600 people from the local community are employed. The LAMP was designed and built in two phases, with full Phase 2 capacity capable of producing up to 22,000 tonnes per annum of separated Rare Earth Oxide (REO) products. Commissioning of the LAMP started in late 2012 and the most valuable product produced at the LAMP is praseodymium/neodymium, NdPr. From mid-2015, the LAMP has been operating at approximately 75% of its NdPr production capacity (Lynas, 2015). This paper was written with the objectives to review the processing flowsheet, the environmental impact associated with the processing of the said ores and the sustainability of the operation.

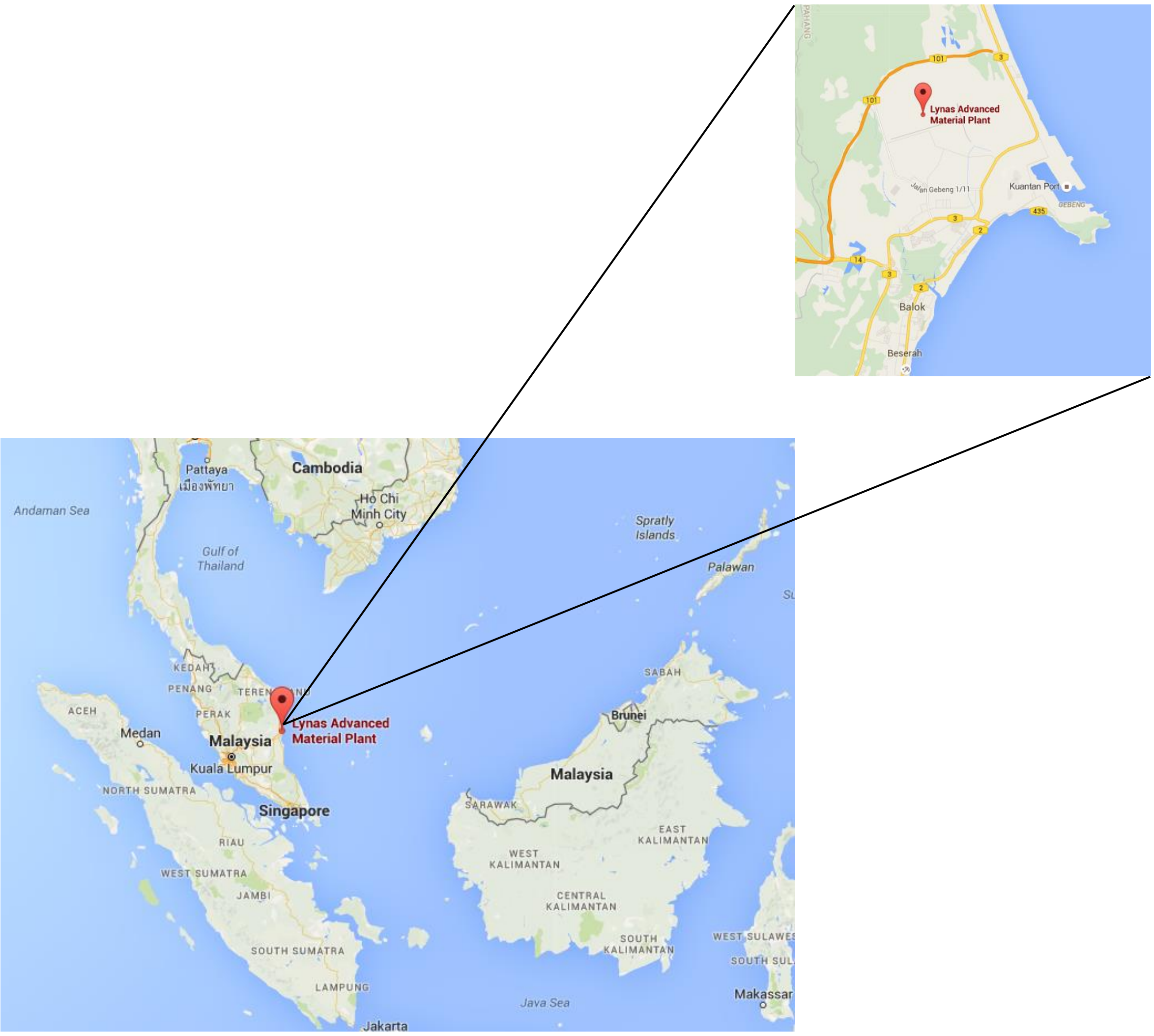

Figure 1: Location of the LAMP facility (Google Maps capture, 2015)

2. SUSTAINABLE DEVELOPMENT IN RARE EARTHS PRODUCTION

While one can consider the urgent need of rare earth minerals for the sake of green technology advancements, one also needs to consider the environmental impacts in the production of the rare-earth minerals and the over use of natural resources to meet the demand for consumption of products with rare-earth minerals. The triple-bottom line impacts of this industry (environmental, economical and social) and negative consequences from such material growth and increasing trends towards green consumerism are important considerations, as governments and industries begin to chart new economic policies with regards to the growth of rare earth industry (Richard, 2010). The global demand for natural resources such as rare-earth minerals and the race for wealth generation amongst some nation-producers, has inevitably caused harm to the environment. Historically, rare earths production has been linked to some pollution events in the vicinity of the processing areas. They are summarised in Table 1.

Table 1: Pollutions events related to rare earth production

Mine	Description of events
Baotou, Inner Mongolia, China	In the village of Xinguang Sancun, farmers have abandoned fields and stopped planting anything but wheat and corn and the population has declined from 2000 to 300 within the past 10 years. A study by the municipal environmental protection agency showed that rare earth minerals were the source of their problems with increased pollution compounded with dozens of new factories and other industrial services (The Guardian, 2012). The Chinese government has committed 4 billion Yuan ($600 million) to clean up the damage caused by the rare earth (RE) sector in this region.
Mountain Pass, California, United States	The Mountain Pass RE mine in California also faced environmental compliance cost challenges which led to its closure during the 1990s, allowing for the Chinese industry to flourish soon thereafter. However, the environmental issues at Mountain Pass involved leakage of a particular piping system used to carry wastewater to an evaporation system. A federal investigation found 60 spills—some unreported—occurred between 1984 and 1998, when the pipeline was shut down. In all, about 600,000 gallons of wastewater flowed onto the desert floor. The mine’s operator at the time was sued by the San Bernardino County district attorney and paid more than $1.4 million in fines and settlements. However, since then the current management of the company has changed the wastewater system completely and through new technologies tailings will be managed much closer to the mine site with a paste-tailings system to avoid piping of wastewater. A field visit by the author to the surrounding areas in January 2013 including interviews with various environmental regulators revealed general satisfaction with the processes being proposed for the site (Ali, 2014). As of 2015, the plant was in full production. However, the company Molycorp filed for bankruptcy in June 2015. The mine is currently shut down and the company’s assets including the mine were to be auctioned off (Hals, 2016).
Jiangxi, China	Additional rare earth mining comes from ion-adsorbed clay deposits, which are particularly prevalent in Southern China and have a considerable environmental footprint in the province of Jiangxi. In 2010 there were 88 rare earth mineral producers in the province’s capital Ganzhou but 90% of them ceased their operations because of weak prices. Jiangxi Province had a reserve of 2.3 Mt of the ion-adsorption RE (Tse, 2011).
Bukit Merah, Malaysia	In the 1980s, the Asian Rare Earth (ARE) refinery company, owned by the Mitsubishi Chemical company, failed to safely dispose of its industrial waste, containing radioactive thorium hydroxide. Workers and the neighbouring community were exposed to ionising radiation, resulting in several birth defects and leukaemia cases among the 11,000 people living in Bukit Merah and Papan, Perak. Seven of the eight cases of leukaemia were fatal. Public protests and legal action eventually forced Mitsubishi Chemical to close its operations in 1992 and agree to an out-of-court settlement with the residents of Bukit Merah (Bradsher, 2011a). The clean-up has cost the company an estimated US$100 million.

Given the importance of REE to the green technology industry, an efficient process that applies sustainable production and consumption is vital for the RE industry. An efficient technology will expand output and mitigate supply chain bottlenecks. The recovery of pre-consumer waste and recycling of post-consumer waste would also assist in the expansion of outputs. Successes in this aspect would compensate for the volatility in the price of rare earth minerals, which is affected due to supply-demand constraints. The eco value chain for the rare earth industry has yet to be well explored while the extent of recycling and reuse of rare-earth related products is limited. For products using rare earth elements, recycling and reuse is quite uncommon, expensive and few opportunities have been capitalized anywhere in the world (Dempsey, 2011). However, research on substitution of rare earth metals with more common materials is underway. Scientists are developing methods to make magnets that are less dependent on rare-earth elements, thus reducing or eliminating entirely the need for rare-earth elements in powerful permanent magnets in products.

There is a need for new producers from developed and developing nations to act responsibly towards managing earth resources collectively, and to view the rare earth metals as one of the many ‘global commons’ or shared resources which should be used responsibly and together (Denmark, 2010). Corporate responsibility that is based on ethical values, and that which questions growth and consumption (Clifton 2011), must be nurtured, in partnership between government and industries, throughout the supply-demand chain, at both the national and global level.

3. PROCESSING AT LYNAS ADVANCED MATERIALS PLANT (LAMP)

The Mount Weld mine in Western Australia, which is the source of the concentrate for the Lynas Advanced Materials Plant (LAMP) facility in Malaysia, is of a lower impact than Bayan Obo, Mountain Pass and adsorbed clay deposits, given the small footprint of the mine itself and the remoteness of the location. The kind of ore being mined (rare earth phosphates: carbonatite, monazite) may have higher thorium content than bastnasite ore from the Chinese or American mines but still far below radiation concerns that may emanate from high grade uranium operations (Ali, 2014).

As a whole, the overall processing steps in producing refined rare earth metals are mining, milling, flotation and further processing, before it becomes the final product. In the mining stage, the extraction of lanthanide concentrate from the Mt. Weld (Western Australia) involves a series of thermal, chemical and physical processes. It is then transferred to LAMP in Malaysia where rare earth mineral extraction begins. Lynas chose Malaysia as the processing site due to lower labour and construction costs (Bradsher, 2011b). The processing of the Mt Weld concentrate involves cracking and leaching, solvent extraction and product finishing (Lynas, 2015). In the cracking and leaching stage, Mount Weld concentrate, which is essentially rare earth phosphate mineral, is mixed with concentrated sulphuric acid and cracked at a high temperature (350 – 450 ^{o}C) to convert the rare earth phosphate minerals to rare earth sulphate. Water is added to the rare earth sulphate in the leaching stage and impurities in the form of iron phosphogypsum are removed. The solution is neutralised to provide rare earth solution as feed to solvent extraction. In the solvent extraction stage, the solution is then mixed with hydrochloric acid (HCl) and the different rare element chlorides are extracted in seven single extraction stages. Solvent Extraction (SX) employs two liquid phases (organic and aqueous) and is carried out in liquid-liquid counter current SX trains to progressively separate the rare earths into groups and individual elements. The main products are light rare earths including praseodymium/neodymium - PrNd; cerium - Ce; lanthanum - La; LaCe - lanthanum cerium solutions, and medium/heavy rare earths (samarium, europium, gadolinium – SEG and other Heavy Rare Earths – HRE) solutions (Lynas, 2015). In the final stage of the process, the rare earth elements in the solution are precipitated as solid carbonates or oxalates. Some are then calcined (cooked) to the respective oxides. The LAMP produces NdPr oxide, Ce carbonate, Ce oxide, LaCe carbonate and LaCe oxide, and SEG oxide. Figure 2 shows a simplified flowsheet of the production process from mining in Mount Weld, Australia to extraction at LAMP in Malaysia.

The different extraction liquids are treated with sodium carbonate, neutralised with magnesium oxide and precipitated with sodium carbonate solution or with oxalic acid, filtered, and either marketed as such or followed by additional stages to yield marketable products. An iron phosphogypsum product is generated from the water leach process. Water from the plant is treated in multi-stages of an acid neutralisation and a solid Magnesium Rich Gypsum product is generated. The iron phosphogypsum and magnesium rich gypsum products are stored on site in dedicated approved facilities. According to Lynas, development work is well underway to develop applications for the re-use of these products (Lynas, 2015).

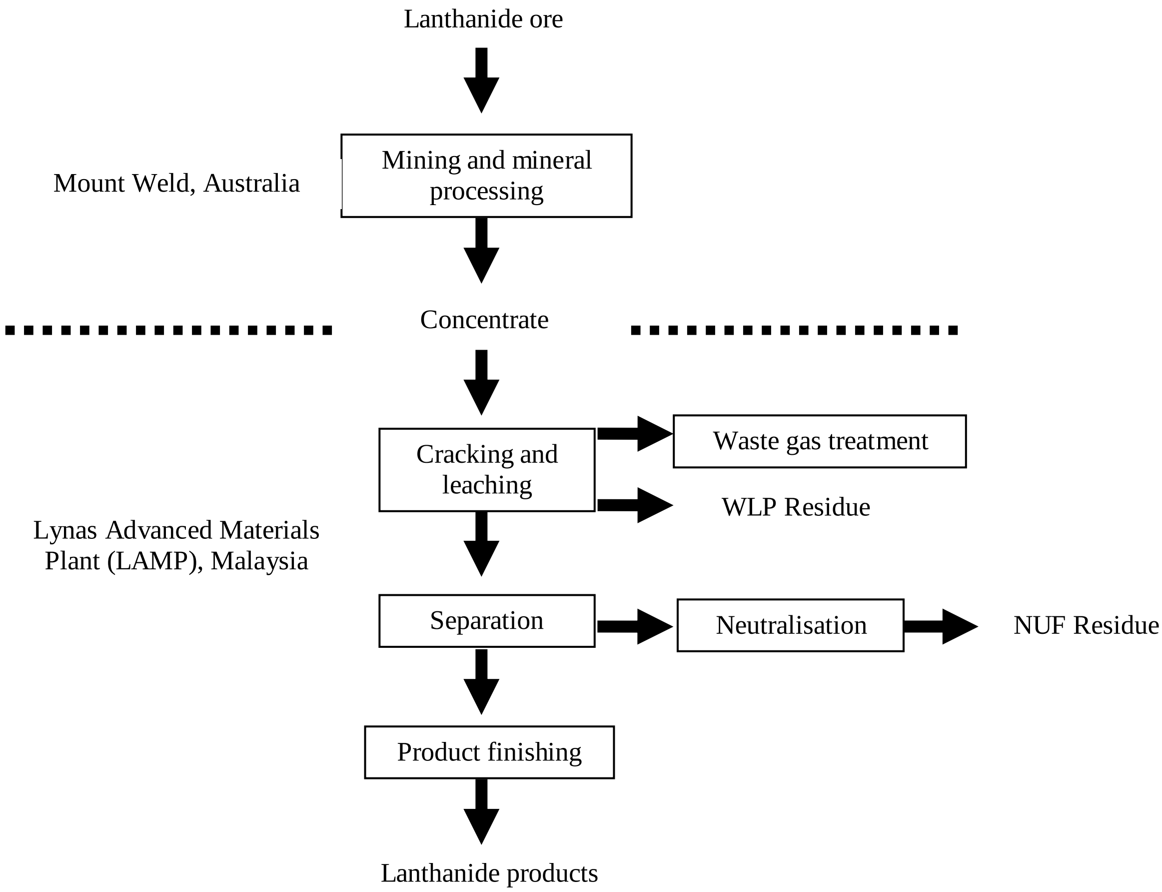

Figure 2: Production flowsheet from Mount Weld, Australia to Lynas Advanced Materials Processing (LAMP) Plant, Malaysia.

4. ENVIRONMENTAL IMPACT

In principle, lanthanide concentrate contains 1600 ppm of thorium and 29 ppm of uranium which is enhanced slightly after ore processing (RIA, 2011). The LAMP plant generates three types of residues, namely Water Leach Purification (WLP) - synthetic gypsum, Flue Gas Desulphurisation (FGD) and Neutralisation Underflow (NUF). The LAMP produces large volume of WLP (32000 tonnes per year) containing thorium and uranium with concentration of 1655 ppm and 22 ppm respectively (RIA, 2011). The radioactive content is suspected to accumulate in WLP residue after REE extraction. Experimental results showed that over 99% of thorium and radium in the feed LC will report to WLP and some uranium will escape to the solvent extraction circuit and will ultimately report to the WLP residue (RIA, 2011). This residue has become a radiological concern to the authorities and public. WLP residue with significant activity concentration of thorium has been classified as radioactive residue. In the wake of worldwide interest of thorium as an alternative future nuclear fuel, there is a proposal for Th to be separated from RE residue and saved as future nuclear fuel. Al-Areqi et al. (2014a) found that thorium concentrations values were higher in LAMP's WLP compared to LC. Also, the WLP residue has high radioactivity of 232Th (7.2Bq/g) which is noticeably high when compared to Malaysian soil natural background. Hence, regulatory control is recommended, as long term radiological impact will take place because of the Th concentration above 1Bq/g. The Lynas residue could also be used as raw materials for other industries if concentrations of the thorium and uranium were to be reduced to natural concentration. Thorium content in the residue can be possibly saved for future nuclear fuel after many stages of radiochemical separations. Research efforts have been made to extract thorium from WLP though this has not reached viable extraction rates (Al-Areqi et al., 2014b). The residue storage facility at Lynas is built above ground level, with high-density plastic lining and a clay layer (Nasruddin and Bustami, 2015). In order to address public concerns, LAMP has installed two Aerosol Monitoring Systems

(AMS), both onsite and in Kuantan, to continuously monitor, measure and clearly demonstrate to the community that the facility will cause no harm.

The International Post-Review mission report by the International Atomic Energy Agency concluded that the Malaysian Counterparts (Atomic Energy Licensing Board - AELB, Government of Malaysia and Lynas Malaysia Sdn. Bhd.) have satisfactorily implemented all the recommendations formulated by the review team of the 2011 mission (IAEA, 2014). The recommendations made by the 2011 review include among others, the requirement of a long term waste management plan before start of operations, a plan for managing the waste from the decommissioning and dismantling of the plant at the end of its life, implementation of exposure and environmental monitoring, criteria development of the flue gas desulphurization (FGD) and neutralization underflow (NUF) residues to be declared non-radioactive for the removal from the site, and the establishment of a fund for covering the cost of the long term management of waste including decommissioning and remediation. The report concluded that "*After the analysis of all documentation provided by the relevant counterpart and examined by the review team and in addition to the observations collected during the site visit and the dialogue sustained with different stakeholders, it became evident that the radiological risks to members of the public and to the environment associated with the operation of Lynas Advanced Material Plant are intrinsically low"*. The protection measures provided to the workers were considered satisfactory and this was recommended to be continuously improved by the operator.

5. PUBLIC REACTION

Proponents of the Lynas project long before its construction have emphasized the economic benefits of the project to the country as well as to the world supply of rare earths. On a global scale, the LAMP facility is the first rare earth processing plant in nearly three decades to be finished outside China, and represents about 8% of the world's rare earth market (Nasruddin and Bustami, 2015). On a national scale, LAMP contributes towards the nation's economic growth objective through the 3rd Industrial Master Plan (MITI, 2010). The facility has created job opportunities as part of Malaysia's aspiration to move towards a high-income status society. In 2012 alone about 350 new jobs for skilled workers were created. The total value of contracts available to Malaysia is RM 1.2 billion, of which RM 513 million is set aside for locally based contractors in the Kuantan area. The expected export revenue generated for Malaysia is estimated at an additional RM 8 billion, contributing up to 1% of the nation's Growth Domestic Product (GDP). Expected spinoffs from the presence of the rare earth industry in Malaysia are the development of downstream and upstream businesses, as well as Malaysia's very own local rare earth industries, which could contribute towards the energy efficient vehicles (EEV) programme (The Academy of Sciences Malaysia and The National Professor's Council, 2011).

The presence of rare earth business in Malaysia has also highlighted the importance of environmental management policy and the role of national and international regulatory bodies. The Ministry of Science, Technology and Innovation (MOSTI), the Ministry of International Trade and Industry (MITI), and the Ministry of Natural Resources and Environment (NRE) are key government ministries responsible for awarding operating licences to the rare earth processing plants in Malaysia. The Atomic Energy Licensing Board (AELB) and the International Atomic Energy Association (IAEA) monitor the radioactive aspects of the operation plant – under the Atomic Energy Licensing Act of 1984, TENORM (Technologically Enhanced Naturally Occurring Radioactive Materials) wastes are monitored (AELB, 2011). Waste streams are regulated by Department of Energy (DOE), under the Environmental Quality Act. All mineral activities are governed by Mineral Development Act of 1994 and the State Mineral Enactment.

There has been however, widespread public opposition to the setting up of the Lynas plant. Many cite the rare earth environmental fiasco in the country dating back to the 80s involving Mitsubishi Chemical Company as an example of negative effects of rare earth processing on the population. The location of the Lynas plant has also generated controversy, it being situated in an area susceptible to flooding (the construction site actually flooded during the late year annual monsoon season of 2011-2012) as well as its proximity to Balok River and the South China Sea. Critics also argue that although the raw material is currently mined at Mount Weld in Western Australia and then exported to Malaysia for processing, Western Australian authorities themselves have refused to entertain the idea of allowing any wastes generated to be shipped back to Western Australia for storage and disposal (Phua and Velu, 2012). Currently, Lynas residues are temporarily stored in specially engineered residual storage facilities (RSF) before conversion into safe commercial products (Bahari, 2013). In terms of its economic impact, opponents of the Lynas plant claimed that the costs would be much greater than the benefits because of likely negative impact on the fisheries industry and the beach tourism industry of the Kuantan region. Opposition to the Lynas project have come from the residents of the Kuantan area as well as citizen action group Save Malaysia Stop Lynas (SMSL) with support from the Malaysian Medical Association and the Pahang Bar association. With support from international environmental groups, local residences have also formed the Green Assembly to oppose the project. LAMP has made some efforts to develop trust amongst the residences in the form of community development programmes. For instance, LAMP is a member of Gebeng Emergency Mutual Aid (GEMA), a voluntary crisis management organization, an alliance between Government agencies and private manufacturers in Gebeng (The Star, 2011). Another example is the LAMP-supported Balok Ivory Tower academic programme for local Malaysian school children.

6. CONCLUSIONS

The future goals of Lynas operations in a developing economy such as Malaysia lie in the integration of sustainable production and environmental management policy. Conducting continuous current and future impact assessment analyses which aim to reduce environmental impact at LAMP, as well as contributing towards new policy actions, would be a great place to start. With leading sustainability performance, the industry could be a good example for other industries in Malaysia with similar or more severe environmental impacts such as bauxite extraction.

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