Sustainable Mining:
Rare Earth Industries

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AKADEMI SAINS MALAYSIA

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Rare Earth Industries

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FOREWORD

Rare earths (REs) are sometimes described as the vitamins of industry. Its small doses can produce powerful effects, proving its vital role in the modern technology. Without the rare earths , consumer culture, green technology, communications, and even aspects of defence and health care would be pale shadows of their current selves. With the increasing demand for RE, a secure source of RE raw materials is critical for the industry. The availability of local sources of RE minerals would greatly facilitate the establishment of upstream mining, midstream and downstream RE-based manufacturing industries.

The ASM Task Force on Sustainable Mining was established in early 2019 to highlight the importance of sustainable mining activities, especially those connected with rare earth deposits, and provide recommendations for such practices. I would like to congratulate the Task Force for producing the Position Paper on Sustainable Mining: of Rare Earth Industries. This paper is ASM's continuing effort on the issues, risks and opportunities related to Lynas, the Australian-owned RE cracking and processing plant in Malaysia. ASM has published few reports on this issue, including Rare Earth Industries: Moving Malaysia's Green Industries Forward (in 3 languages - 2011), Revitalising the Rare Earth Mineral Industry: A Strategic Industry (2012), Proceedings of the International Symposium On Rare Earths and on the Intellectual Discourse: Green Opportunities In Rare Earth Industries (2012), and culminating in its flagship publication entitled Blueprint for The Establishment of Rare Earth-Based Industries in Malaysia: A Strategic New Source for Economic Growth (2014).

The production of this Position Paper would not have been possible without the strong support and co-operation from members of the Task Force and other relevant organisations. I hope this Position Paper would benefit policymakers, state governments as well as industry players to harness science, technology and innovation towards sustainable solutions for the mining industry.

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President
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PREFACE

With the increasing demand and interest on RE minerals and their purified oxides, it now presents Malaysia with the opportunity to be among the global players in developing its local RE deposits and at the same time revitalise its RE mining and processing activities. This aspiration is in line with its view that RE elements can form the basis of many value-added downstream industries in the country, especially to the industries that can contribute to the nation's green economy, benefitted the upstream (mining and primary processing) and mid-stream (secondary processing and related activities) industries, while providing vast opportunities for employment to our local youth in advanced technologies.

The main objective of this Position Paper is to provide insights on the sustainable mining of the RE ores and the benefits of establishing and developing a RE industry in Malaysia. The availability of local sources of RE minerals would greatly facilitate the establishment of midstream and downstream RE-based processing and manufacturing activities, which will also benefit other sectors, especially Malaysia's Green Economy.

This Position Paper also establishes firmly and through scientific evidence on the current issues pertaining to the operation of the Lynas Advanced Material Plant (LAMP) at Gebeng so that an objective benefit and risk assessment can be made by policymakers based on clear scientific evidence.

Finally, we are grateful to all the Task Force members for providing relevant support and useful feedback, all of which helped to develop a deeper understanding of the challenges and potential action plan expressed in this Position Paper. It is hoped that this Paper will serve as a useful reference in the sustainable mining of RE ores and their processing as well as the promoting of RE-based industries in Malaysia.

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LIST OF FIGURES AND TABLES

LIST OF ACRONYMS

AELB	Atomic Energy Licensing Board
ASM	Academy of Sciences Malaysia
DOE	Department of Environment
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
HREE	Heavy Rare Earth Elements
IAEA	International Atomic Energy Agency
JMG	Jabatan Mineral dan Geosains (Minerals and Geoscience Department)
KATS	Ministry of Water, Land and Natural Resources
LAMP	Lynas Advanced Material Plant
LREE	Light Rare Earth Elements
MIDA	Malaysian Investment Development Authority
NUF	Neutralisation Underflow Residue
OEM	Original Equipment Manufacturer
RE	Rare Earths
REE	Rare Earth Elements
REO	Rare Earth Oxides
SOP	Standard Operating Procedures
TAFE	Technical and Further Education
TVET	Technical Vocational and Education Training
UKM	Universiti Kebangsaan Malaysia
UMS	Universiti Malaysia Sabah
UPM	Universiti Putra Malaysia
UTeM	Universiti Teknikal Malaysia Melaka
UTM	Universiti Teknologi Malaysia
WLP	Water Leach Purification

EXECUTIVE SUMMARY

Lynas Corp's RE processing plant in Gebeng, Kuantan has been operating since 2012. Lynas, being the only significant producer of RE outside of China, produces lanthanides, the name for a group of 17 elements crucial in the production of high-end industries of batteries, computers, televisions, magnets and smartphones. However, it continued to raise mixed reactions among Malaysians due to its radioactive-bearing waste disposal plan. Lynas was hit with the allegation of heavy metals in groundwater. However, this allegation is unfounded as the ore concentrated being delivered to Gebeng was found to have a very low level of nickel and other heavy metals.

In August 2019, the Government of Malaysia had renewed Lynas Malaysia's operating license for another six months with certain conditions attached. Lynas was required to present their plan in regards to its processing of waste. Lynas also would have to identify a site for a permanent storage facility (PDF) for its low-level radioactive waste. Otherwise, Lynas must find a country that is willing to take the waste. The Australian Government and the Western Australia State Government, however, had informed Malaysia that they will not be accepting Lynas' radioactive Water Leach Purification (WLP) residue. In addition, all research and development (R&D) activities on the WLP radioactive residue as CondiSoil for agriculture need to be terminated. Lynas needs to submit 0.5% of the gross sales annually designated for previous R&D efforts to the Government of Malaysia as additional collateral up until the cracking and leaching facility is in operation overseas. In the statement by the Atomic Energy Licensing Board (AELB) issued on 15th August 2019, the conditions were decided based on the recommendation made by the Lynas Operation Executive Review Committee in its report issued November 2018.

The RE elements have been named "The Vitamins of Modern Industry". They are vital to many modern technologies, help fuel global economic growth, maintain high standards of living and are used in medical equipment. In recent years, the demand for REs has been increasing, particularly for use in energy efficiency and high technologies. Not only are they capable of meeting the needs of being faster, lighter, smaller and more efficient, RE also plays an important role in developing green industries.

The move by various parties to push for the closure of the LAMP in Gebeng, ostensibly because of its radioactive wastes, is not a healthy development for Malaysia as it strives to be a regional centre for high-technology, capital intensive, knowledge-driven industries (MIDA, 2013). MIDA, in fact, had identified RE-based downstream industries in the value chain ranging from RE Metal Oxide production to RE Metal production to manufacturing RE Magnet blocks to manufacturing RE Magnets and RE Products to Applications and End Users.

Malaysia is blessed because it has the basic starting block of the full ecosystem. From the occurrence of ion-adsorption clays, containing essentially radioactive-free RE elements, to processing and cracking of the RE elements (both heavy and light as is being undertaken by Lynas) for the establishment of downstream RE-based industries. Malaysia also has RE bearing minerals of monazite and xenotime, but these minerals also contain thorium and uranium in amounts exceeding the amounts in the Lynas lanthanides ore concentrates.

As the country's high technology industry continues to develop and expand, a secure supply of RE raw material is critical; otherwise, the industry would be vulnerable to vagaries of the international RE supply market. The upstream and downstream of mining industries will be an advantage to us. The creation and establishment of these multi-billion dollar industries in Malaysia would augur well for the continuous development of its human capital (from mining to processing to manufacturing) as well as contributing to the national GDP.

In summary,

- There is no concrete, evidence-based data to prove any significant negative health impact caused by the Lynas operations. However, ASM proposes to initiate and lead a health monitoring and baseline studies funded by relevant bodies or agencies to make sure the health and safety of nearby residents are not affected.
- The journey towards an advanced high-technology nation will inevitably involve certain risks to be faced upfront, which with the appropriate science and technology interventions, can be minimised or neutralised.
- Malaysia is currently the only nation globally, outside China, with an RE processing plant. Closing down LAMP will send a strong negative message to advanced nations intending to invest in high-tech high-risk high-growth industries in Malaysia.
- The wastes (both the WLP and NUF) from Lynas have a value which can be sold as part of the circular-economy approach with the current low amount of radioactivity in the WLP to be further lowered by admixing with barren soil.
- Insisting for certain countries to take back "their" wastes can send a wrong message to them. They may, in return, insist Malaysia take back its palm oil, rubber and plastic lining wastes from their countries.
- A specific policy on RE exploration and mining should be developed by KATS. This policy must include an environmentally-sustainable set of strict and enforceable Standard Operating Procedures and guidelines to mine and process the ion-adsorption clays, so as to enhance the regional exploration for REs in ion-adsorption clay deposits nation-wide.
- Encourage mining companies in Malaysia to undertake the detailed exploration and mining of ion-adsorption clay deposits in Malaysia with KATS assisting states through providing technical assistance on mining and processing of ion-adsorption clays as well as in the issuance of RE mining licenses to these companies.
- Invite RE specialist companies to Malaysia to establish both mid-stream and down-stream RE industries (plants) to process high-purity RE oxides from Lynas and RE sulphates from Malaysian ion-adsorption clay deposits.
- The employment opportunities for high-skilled (from universities) and medium-skilled (from TVET institutions) Malaysians in these plants is immense.

1.0 INTRODUCTION

In a report commissioned by ASM entitled Revitalising The Rare Earth Mineral Industry In Malaysia: A Strategic Industry, it was pointed out that Malaysia's aspiration to become a high-income nation is very much dependent on the success of its involvement in high technology and green technology. Whilst it is true that many high-income nations do not have RE mineral industry in their own backyard, it can also be said that they have now realised that they are heavily dependent on the RE raw material producers. Realising how critical it is to have a secured supply of RE raw materials and how vulnerable their high technology industries (and their economies) are to such supplies, these countries have embarked on exploration programmes and outward investments to hedge against future threats.

In another ASM publication, A Blueprint for the Establishment of Rare Earths Industries in Malaysia – A New Source of Economic Growth, it was highlighted that the opportunity exists for Malaysia to become a centre for the manufacturing of RE permanent magnets, phosphors, lasers, and oil-refining catalysts. In order for that to come about, Malaysia must first produce domestically or acquire control over the minerals from which critical REs can be extracted. It will then be necessary for the Malaysian industry to learn how to extract the desired RE elements from these minerals, separate the individual REs from each other and purify them to a level for industrial use. At this point, the separated and purified REs, a valuable group of commodities with a global market, will be in production and be able to be sold globally "as is."

The next step in the creation of a domestic Malaysian RE supply chain will be the creation of a domestic industry that produces, from the separated and purified individual rare earth elements, the individual high purity RE metals, alloys (for magnets andsteel-making), phosphors, and fine chemicals for the production of lasers, medical equipment, industrial equipment, and fluid cracking catalysts (for the oil refining industry). These "raw materials" produced at this stage will also be saleable into the global high tech market "as is."

Finally, a domestic Malaysian high-tech consumer and industrial end-use product industry will be created to manufacture and supply RE permanent magnets to the OEM automotive industry, the aerospace industry, the power generation industry, and the consumer portable electronic industries. Many of these industries already exist in Malaysia, such as OEM automotive and computer hard-disk drive manufacturing. These industries would be the large end-users of RE permanent magnet-based components, such as electric motors and generators.

The existing domestic Malaysian end-users of RE-enabled products will give the domestic RE component manufacturers a solid market anchor.

1.1 Rare Earth Elements

The rare earth elements (REEs) comprise the 15 elements in the Lanthanide Group in the Periodic Table with atomic numbers 57 to 71 as well as yttrium (39) and scandium (21), both of which display chemical properties and behaviour akin to REEs. These elements are normally divided into two categories, namely the light rare earth elements (LREEs) comprising elements with atomic numbers ranging from 57 to 63, and heavy rare earth elements (HREEs) comprising elements with atomic numbers ranging from 64 to 71. Yttrium is categorised as an HREE. Scandium has very few applications and is normally not included in discussions. RE minerals refer to minerals which contain a significant amount of REEs either as part of the crystal structure or as ionic substitution in the lattice. Unlike gold or silver, for example, REEs do not occur in nature as metallic elements, but they are found in a variety of minerals. These minerals are not as abundant as rock forming minerals, such as quartz and feldspar, but they are present in a wide variety of rocks, in most cases as accessory minerals. Bastnaesite, monazite, xenotime and loparite are the most common commercially extracted RE-bearing minerals.

1.2 Rare Earth Minerals as a Global Strategic Commodity

The ASM publication entitled A Blueprint for the Establishment of Rare Earths Industries in Malaysia – A New Source of Economic Growth (2014), reported that, since 2008, there has been a revival of interest in the RE elements due primarily to the rapid growth of the East Asian consumer economy. This has resulted in a dramatic increase in the demand for miniaturised electronic devices for communications, data processing, and entertainment.

During the last thirty years, the revival of the mining of the RE elements moved from being principally in the United States to being almost entirely in the People's Republic of China. This was originally an economic decision driven by low-priced Chinese RE ore concentrates. As non-Chinese RE mining shut down, the American domestic total RE supply chain lost its mining anchor. This drove the refining of the RE and the fabricating of RE-enabled components to be moved to China so as to have easy access to the necessary rare materials. There then followed logically the outsourcing of the manufacturing of devices using rare earth enabled components from the USA to China.

Based on R&D in the late 1970s, the OEM automotive industry began to switch from ferrite- and alnico-based permanent magnet motors and generators to RE permanent magnet-based devices in the early 1980s. This was driven by the need to minimise the weight of motor vehicles while losing no efficiency in order to decrease fuel consumption and increase thereby fuel economy.

At the same time, in the early 1980s, the personal computer made its debut in the USA and Europe. Manufacturing engineers soon realised that RE permanent magnets could enable a dramatic decrease in the size and weight of the read/write heads on hard disc drives thus allowing for a substantial increase in the memory capacity and operating speed of such devices. Shortly after that, audio and telephone equipment designers realised that RE permanent magnets could dramatically reduce the size of speakers without compromising the quality or intensity of sound reproduction.

The RE-enabled miniaturisation of consumer and industrial devices was underway, but this was after the new production of the RE and the refining and fabricating of industrial forms of them had already moved to China. By 2002, the entirety of the American and most of the European domestic and regional RE supply chains had moved to China.

It took only until 2007 for alarms to go off in the USA and Europe when it became obvious that the military needs for RE permanent magnets, lasers, and SONAR devices were now totally susceptible to the whims of the People's Republic of China. Wall Street speculators spun this problem completely out of proportion and a one-dimensional approach, the reopening of a former mine and the exploration for new ore bodies, drowned out the common sense that any revival of a non-Chinese RE industry would require that the total RE supply chain be reconstructed outside of China.

What was also overlooked by Wall Street speculators was the fact that only certain of the RE was critical and the most critical of these, dysprosium, had never been produced commercially outside of China. The shameless promotion of a few large deposits of the common light REs, lanthanum, cerium, praseodymium and neodymium completely drowned out the fact that sources of the most important REs, terbium, dysprosium, and yttrium, were not being developed even though without them there could be no domestic total RE supply chain outside of China.

Today, the fervour begun in 2007 for RE production has subsided, and a reassessment by long-range planners and investors is underway. It is clear that no single deposit can support a total domestic supply chain for a RE industry anywhere. Such supply chain will require sources of the light REs and the heavy REs along with chemical engineering facilities capable of separating large quantities of light REs and much smaller quantities of heavy REs from each other, respectively. In addition, facilities will be needed to produce pure RE metals and alloys from the separated chemical forms of all of the REs. The next step will be facilities to produce RE permanent magnet alloys, lasing chemicals, and phosphor chemicals. Finally, manufacturers of RE enabled devices will be needed to fabricate RE permanent magnets, lasers, and phosphors for use in consumer, industrial, and military end-use products.

All of this is done only in China. The Chinese domestic market for RE-enabled devices is growing more rapidly than the global market. The Chinese have made it clear that their domestic needs will come first and foremost. China is the only producer today of terbium, dysprosium, and yttrium. If these materials are cut off, then there can be no non-Chinese domestic total supply chain anywhere else unless non-Chinese heavy RE production, refining, and fabricating are given immediate priority.

The Blueprint categorically states that Malaysia is uniquely situated to take advantage of this dilemma. Malaysia has been an RE producer and exporter for a long time; it now has the largest single light RE separation facility in the world. The facility can be supplied indefinitely from Australian resources. Malaysia has good sources of heavy REs and the ability to attract specialised refining and fabricating vendors to cover the entire spectrum of rare earth enabled products.

A pilot programme must be initiated and funded immediately and this blueprint details how that can be achieved. Is there enough future global and/or regional demand for the RE to justify an investment by Malaysians, privately with public support, to create a total domestic RE supply chain within the country? This blueprint in fact gives a definitive answer to the question "Can Malaysia build a domestic total rare earth supply chain?" The answer is yes. As for the larger question "Is it the right thing for Malaysia to so right now" the answer is emphatically yes.

1.3. Global Sources of Rare Earth Minerals

ASM's Report entitled Revitalising the Rare Earth Mineral Industry in Malaysia: A Strategic Industry (2012) stated that REEs and RE-bearing minerals occur in various forms and types of deposits. Four main types of deposits can be recognised, namely:

(i) Those present as hard rock deposits
(ii) Those associated with placer deposits
(iii) Those associated with ion adsorption clay deposits
(iv) Those associated with deep-sea mud deposits

The first three have already been mined commercially.

1.3.1 RE deposits associated with hard rock

The principal concentrations of REEs in hard rocks are associated with uncommon varieties of igneous rocks, namely alkaline igneous rocks and carbonatites. Alkaline igneous rocks account for less than 1% of all igneous rocks.

Carbonatites are typically associated with undersaturated (low silica) igneous rocks that are either alkali (Na_2O and K_2O)-rich, ferric iron (Fe_2O_3)-rich and zirconium-rich agpaitic rocks or alkali-poor Fe-CaO-Mg-rich and zirconium-poor miaskitic rocks. The most famous example of an RE producing carbonatite deposit is the Bayan Obo deposit in Inner Mongolia, China. Some 530 carbonatites have been discovered worldwide, half of which are located in the continent of Africa.

Other rock types which have been known to host a significant amount of REEs include stratiform phosphate deposits (e.g. in Mount Weld, Australia), pegmatites, replacement type deposits, various types of especially high-grade metamorphic rocks and porphyries.

1.3.2 RE deposits associated with placers

Erosion of crystalline rocks releases monazite and other heavy minerals, including xenotime, for transport and accumulation in sedimentary rocks. Locally, the processes of erosion and transportation may be varied and complicated, the detrital monazite travelling through several cycles of transport and deposition before being lodged in the deposits where it is presently found. Processes of glacial and wind erosion and transport are known to have released, moved and concentrated monazite, but the most effective agents are those related to rock weathering, fluvial transport and accumulation of weathered material on beaches. Rock weathering is especially effective in warm, humid regions where chemical weathering exceeds the rate of erosion and thick mantles of thoroughly weathered residuum accumulate. Chemical weathering reduces the variety of heavy minerals in the crystalline rocks and residuum until only the most inert ones remain to form eluvial deposits and to be washed into streams. In the streams, the heavy minerals are further winnowed and mechanically concentrated into fluviatile placers.

Stream placers are not static deposits. A constant flow of monazite-bearing sediment moves downstream to interior basins or to the sea where the discharged sedimentary materials are further sorted. The tide, along-shore currents, waves, and wind continue to work and rework the monazite. These processes tend to concentrate it with other resistant heavy minerals in beach and dune placers. Such beach and dune placers are important sources of monazite. Recent placers are generally in unconsolidated sediments, such as in the Kinta Valley and Klang Valley in Peninsular Malaysia and Travancore, Kerala, in India. Fossil placers are preserved in lithified sediments of many ages, and accessory detrital monazite is found in sedimentary rocks of all ages from Precambrian to Quaternary. Fossil placers are especially common in rocks of Precambrian, Cambrian, Cretaceous and Tertiary age.

1.3.3 RE deposits associated with ion adsorption clays

Ores with exchangeable REEs have become an important RE mineral resource in China since the early 1970s. The total reserve of this type of deposit has reached millions of tonnes of RE oxides, and they form particularly significant resources for HREEs.

In China, the ion adsorption type RE clay (sometimes loosely referred to as RE clay) deposits occur mainly in the areas south of latitude 28oN, namely in the provinces of Jiangxi, Guangdong, Guangxi, Hunan and Fujian, with about 90% of the known resources in China located in the first three named provinces. Generally, the weathering profiles in these regions commonly range from 15 to 35 m but can be as much as 60 m locally. Known areas of RE mineralisation in clay deposits total about 90,000 km2, and a total of 214 RE clay deposits have been explored. The annual output (2010) of HREEs from this type of RE clay mineralisation has reached some 45,000 tonnes. The south China RE clay reserve is expected to be depleted in 10 to 15 years based on the present-day estimate of known deposits and rate of extraction.

Accumulation of RE clays in the weathering profiles of the south China granitic rocks is strongly controlled by the resistance to weathering of the principal RE-bearing accessory minerals in the parent rock. Only a third of total REEs is incorporated in the rock-forming minerals. Mineralisation with exchangeable REEs occurs more commonly in weathering profiles developed in granitic rocks within which most of the REEs are incorporated in accessory minerals such as doverite and parisite which are weakly resistant to weathering.

In equilibrium with atmospheric CO2, meteoric water is generally weakly acidic. Meteoric water percolating through a layer of humus-rich topsoil could become more acidic and corrosive and can carry a variety of cations, including REEs. However, organic acids have been found to play only a minor role in REE leaching and migration during weathering processes. Differences in the relative affinities (i.e. relative affinities between the ions for surface adsorption on to particles and complexation to the ligand in solution) of REEs are ultimately caused by a basic chemical property, the lanthanide contraction, which is the systematic and gradual trend in REE3+ stability constants which, in turn, results in LREE3+ being preferentially adsorbed to surfaces and HREE3+ being retained in solution. This causes the HREEs to preferentially migrate and accumulate in the deeper part of the weathering profile.

Mineralisation of ion-exchangeable REEs has been found in weathering profiles of various rock types, ranging in composition from granite to acidic volcanic rocks and lamprophyre in southern China. The majority of the known REE mineralisation occurs however in the weathering profiles of granitic rocks, especially S-type granites of Mesozoic age.

Under warm and humid climate conditions, continual leaching coupled with a low rate of denudation resulted in the REE depletion in the top layer and enrichment in subsurface layers of the well-developed weathering profiles of granitic rocks. The advantages of RE clay deposits are:

(i) No "cracking" of RE minerals is required
(ii) The REEs are easily eluted from the clay, making it viable even to mine clays containing only 500 ppm REEs
(iii) The REEs consist predominantly of the more valuable HREEs
(iv) Such deposits contain very low to nil amounts of radioactive thorium and uranium

1.3.4 RE deposits associated with deep-sea mud

In June 2012, scientists from the University of Tokyo, Japan announced that they had found a large deposit of RE minerals in the Pacific seabed – enough to supply its high technology industries for more than 200 years. Similar initiatives to explore for REEs in the deep-sea bed are being undertaken by other countries.

In 2011, the International Sea Bed Authority (ISBA) approved an application by China Ocean Mineral Resources Research and Development Association (COMRA) to undertake exploration for polymetallic sulphides in the South-West Indian Ocean Ridge, situated in the Indian sector of the Southern Ocean. Responding to China's rapid strides in extending its strategic interest in deep-sea mining in the Indian Ocean, India in July 2012, announced its own plans for deep-sea exploration for RE minerals in the region.

The Japanese announcement, however, was not received without scepticism. Although the extent of the Japanese find could not be disputed, it would be worthwhile to take note of a cautionary remark from Professor Frank Sansone of the University of Hawaii - "There's a big difference between saying that the elements exist in large amounts and being able to appropriately, economically and environmentally extract the material".

1.4. Uses and Importance of Rare Earth Metals and Compounds

RE elements have physical and chemical properties which make them ideally suited for, and critical in, high technology and green technology applications. These include:

- Chemical – unique electron configuration
- Catalytic – oxygen storage and release
- Magnetic – high magnetic anisotropy and large magnetic moment
- Optical – fluorescence, high refractive index
- Electrical – high conductivity
- Metallurgical – efficient hydrogen storage in rare earth alloy

The five REEs that are essential to green technologies are neodymium (Nd), dysprosium (Dy), terbium (Tb), europium (Eu) and yttrium (Y).

The vast variety of uses, not only in defence technology but in everyday household and industrial uses and products, such as in computers, lasers, chemical processing etc., show their importance in catalysing Industry 4.0 as well as in the Internet of Things. The uses of all the REEs are shown in Figure 1 below:

WHAT ARE THEY USED FOR ?

SCANDIUM
Aerospace components, aluminium alloys

YTTRIUM
Lasers, TV and computer displays, microwave filters

LANTHANUM
Oil refining, hybrid-car batteries, camera lenses

CERIUM
Catalytic converters, oil refining, glass-lens production

PRASEODYMIUM
Aircraft engines, carbon arc lights

NEODYMIUM
Computer hard drives, cell phones, high-power magnets

PROMETHIUM
Portable x-ray machines, nuclear batteries

SAMARIUM
High-power magnets, ethanol, PCB cleansers

EUROPIUM
TV and computer displays, lasers, optical electronics

GADOLINIUM
Cancer therapy, MRI contrast agent

TERBIUM
Solid-state electronics, sonar systems

DYSPROSIUM
Lasers, nuclear-reactor control rods, high-power magnets

HOLMIUM
High-power magnets, lasers

ERBIUM
Fiber optics, nuclear-reactor control rods

THULIUM
X-ray machines, superconductors

YTTERBIUM
Portable x-ray machines, lasers

LUTETIUM
Chemical processing, LED lightbulbs

Figure 1 RE Elements and Their Uses

1.5 Strategic Importance of the Malaysian RE Mineral Industry for Its Green Economy

As the country's high technology industry continues to develop and expand, more RE raw materials will be needed. Secured supply of RE raw material is critical; otherwise, the industry would be vulnerable to vagaries of the international RE supply market. It is this criticality and vulnerability that makes the RE mineral industry in Malaysia strategic. The importance of REEs is reflected in the price of the RE metals /oxides, as shown below:

Table 1 Prices of REE Metals / Oxides (as of 27th May 2019)

	Heavy Rare Earth Metals	**Purity**	**Recent Price**
27.May.19	Europium Oxide (Eu_2O_3)	>99.5%	250.0
27.May.19	Gadolinium (Gd)	>99.9%	163.0
27.May.19	Gadolinium Oxide (Gd_2O_3)	>99.5%	205,000
27.May.19	Terbium (Tb)	>99.9%	4,550
27.May.19	Terbium Oxide (Tb_4O_7)	>99.9%	3,625
27.May.19	Dysprosium (Dy)	>99%	2,325
27.May.19	Dysprosium Oxide (Dy_2O_3)	>99.5%	1,975
27.May.19	Erbium (Er)	>99.9%	194.0
27.May.19	Erbium Oxide (Er_2O_3)	>99.5%	157,500
27.May.19	Yttrium (Y)	>99.9%	225.0
27.May.19	Yttrium Oxide (Y_2O_3)	>99.99%	19,000
27.May.19	Scandium (Sc)	>99.99%	22,300
27.May.19	Scandium Oxide (Sc_2O_3)	>99.99%	7,050
27.May.19	Battery Grade Mischmetal	>99%	145,000
	Light Rare Earth Metals		
27.May.19	Lanthanum (La)	>99%	35,500
27.May.19	Lanthanum Oxide (La_2O_3)	>99.5%	12,250
27.May.19	Cerium (Ce)	>99%	34,500
27.May.19	Cerium Oxide (CeO_2)	>99.5%	12,250
27.May.19	Praseodymium (Pr)	>99%	690,000
27.May.19	Praseodymium Oxide (Pr_2O_3)	>99.5%	355,000
27.May.19	Didymium Oxide ($Nd_2O_3Pr_2O_3$)		335,000
27.May.19	Neodymium (Nd)	>99.5%	450,000
27.May.19	Neodymium Oxide (Nd_2O_3)	>99.5%	335,000
27.May.19	Samarium (Sm)	>99.5%	98.0
27.May.19	Samarium Oxide (Sm_2O_3)	>99.9%	12,500

Year-to-Date%	Units		Price as at 31.Dec.2018
-3.8%	¥ RMB / kg.	Shanghai Metals Mkt.	260.0
48.2%	$ USD / 10 grams	Millipore-Sigma	110.0
53.6%	¥ RMB / Tonne	Shanghai Metals Mkt.	133,500
17.4%	¥ RMB / kg.	Shanghai Metals Mkt.	3,875
23.5%	¥ RMB / kg.	Shanghai Metals Mkt.	2,935
40.5%	¥ RMB / kg.	Shanghai Metals Mkt.	1,655
63.2%	¥ RMB / kg.	Shanghai Metals Mkt.	1,210
76.4%	$ USD / 10 grams	Millipore-Sigma	110.0
5.4%	¥ RMB / Tonne	Shanghai Metals Mkt.	149.500
0	¥ RMB / kg.	Shanghai Metals Mkt.	225.0
0	¥ RMB / Tonne	Shanghai Metals Mkt.	19,000
0	¥ RMB / kg.	Instut für seltene Erden	22,300
0	¥ RMB / kg.	Instut für seltene Erden	7,050
0	¥ RMB / Tonne	Shanghai Metals Mkt.	145,000
-5.3%	¥ RMB / Tonne	Shanghai Metals Mkt.	37,500
-3.9%	¥ RMB / Tonne	Shanghai Metals Mkt.	12,750
-5.5%	¥ RMB / Tonne	Shanghai Metals Mkt.	36,500
-5.8%	¥ RMB / Tonne	Shanghai Metals Mkt.	13,000
4.5%	¥ RMB / Tonne	Shanghai Metals Mkt.	660,000
-10.7%	¥ RMB / Tonne	Shanghai Metals Mkt.	397,500
7.5%	¥ RMB / Tonne	Shanghai Metals Mkt.	311,500
13.1%	¥ RMB / Tonne	Shanghai Metals Mkt.	398,000
7.5%	¥ RMB / Tonne	Shanghai Metals Mkt.	311,500
0	¥ RMB / kg.	Instut für seltene Erden	98.0
0	¥ RMB / Tonne	Shanghai Metals Mkt.	12,500

Source: https://mineralprices.com/rare-earth-metals/ (accessed on 1st July 2019)

1.6 The occurrence of RE Elements in Malaysia

RE elements are termed "rare" not because of its low abundance in the earth's crust. In fact, in terms of abundance, thulium and lutetium, which are the two least abundant REEs each have an average crustal abundance that is nearly 200 times greater than that of gold. The term "rare" is often attributed to the fact that REEs are not commonly found in sufficient concentrations such that they can be mined for the REEs themselves. They are commonly produced as a by- or co-product of mining of another mineral. In nature, REEs and RE minerals occur in various forms and types of deposits. Four main types of deposits can be recognised, in their order of importance, namely:

(i) On-shore alluvial (placer) xenotime and monazite
(ii) Ion adsorption clays containing RE elements (REEs)
(iii) RE minerals and REEs in marine sediments
(iv) RE minerals in primary sources

1.6.1 On-shore alluvial (placer) deposits of xenotime and monazite

Historically, Malaysia's RE mineral production has always been associated with alluvial, or placer, tin mining. Monazite and xenotime are produced from the re-treatment of tin tailings (amang). Presently, Malaysia's involvement in the RE mineral industry is almost exclusively limited to the production of monazite and xenotime through the processing of local and imported amang. Monazite and xenotime are known to occur ubiquitously throughout the Peninsula in the stream sediments draining granitic areas and as part of the heavy mineral assemblages in the alluvium in coastal areas, especially in the Kinta and Kuala Lumpur tin fields. Although they have not been found to be present in concentrations high enough to be mined by themselves, monazite and xenotime have nevertheless been produced lucratively as a by-product of alluvial tin mining.

Thus, placer monazite and xenotime constitute potential RE resources in Peninsular Malaysia. The search and identification of alluvial areas with high concentrations of monazite and xenotime should be continued. Increased alluvial tin mining activities will invariably result in the production of more amang and consequently more monazite and xenotime being unearthed from the ground. Thus, the revitalisation of the upstream RE industry would invariably be tied to initiatives to revitalise alluvial tin mining. It is encouraging, therefore, to note from recent media quoting the Minister of Water, Land and Natural Resources Malaysia, "with the current high tin metal price (some USD$20,000/tonne), the government is planning to revive the tin mining industry in Malaysia".

1.6.2 Ion-Adsorption Clay Deposits containing RE elements (REEs)

Ion-adsorption type clays have been known to host high concentrations of REEs. Thus far, only the deposits in south China are in commercial production, but such deposits have been discovered elsewhere, for example, in Laos and Vietnam. The main characteristics of RE clay deposits are that it is commonly found in tropical areas with hot and wet climatic conditions and deep weathering, and they are usually associated with tin-bearing granites. The advantage of these deposits is that they are radioactive-free, and therefore, the radioactive elements of thorium and uranium are absent.

Papangelakisi and Moldoveanu (2014) reported that due to various weathering conditions (i.e. nature of host rocks, water and soil pH, temperature, pressure, redox conditions), there are three main categories of REEs present in the ion-adsorption clays:

(i) Colloid phase: REE deposited as insoluble oxides or hydroxides or as part of colloidal polymeric organometallic compounds

(ii) Exchangeable phase: REE occur as soluble free cations/hydrated cations, or part of positively-charged complexes in solution adsorbed species on clays, and account for 60-90% of the total content of RE in ores and can be recovered by ion-exchange leaching with monovalent salts

(iii) Mineral phase: REE part of solid fine particles with same mineral matrix as the host rocks (REE part of the crystal lattice). This phase usually accounts for the balance from the ion-exchangeable phase towards the TREE content and can be recovered only by aggressive conditions (alkaline bake and acid leach).

Malaysia has similar climatic conditions and also a large expanse of deeply weathered tin-bearing granite. It is for these reasons that the potential of RE clay deposits has been identified for further investigation. Prior to 2013, no work has ever been done to explore for ion-adsorption clays in Malaysia, but in early 2013, Watanabe, a Japanese Geologist, collected some soil samples from a weathered granite outcrop in the Bukit Tinggi area for analyses in Japan. The REE distribution profiles obtained were found to be promising.

If such deposits of mineable grade are found, it will be a big boost to the mining industry. Such deposits usually host HREEs which are in demand and also do not come with the issue of radioactive waste disposal. The setting up of the highly desired midstream RE processing facilities in Malaysia would be less of a problem (and in this aspect, the presence of the LAMP in Gebeng, Kuantan, is regarded as a step in the right direction) and pave the way for the further development of the downstream RE industry. In this regard, in a preliminary study on ion-adsorption clays in areas underlain by granites in Perak, Terengganu, Pahang and Johor, undertaken jointly by ASM and JMG Malaysia in 2014/2015, of the 136 samples collected from the over-burden (containing the ion-adsorption clays) overlying the granites, 60 selected samples were analysed. The results show that all the samples contained encouraging values of Light REEs and Heavy REEs (Table 2).

In a related development, ASM was informed that there is a proposed RE mine, planned to work on ion-adsorption clays, in Tanah Merah, Kelantan. This mine has yet to obtain a mining license from JMG.

To date, China is the only country where REE-hosted ion adsorption clay deposits have been exploited commercially. Most of the mining operations are in South China. The deposits are located mostly in remote mountainous areas; discovered and mined by local villagers using primitive methods much like artisanal mining in other countries. Nevertheless, collectively they constitute the largest producer of HREEs in the world.

Two types of mining methods are practised in south China. The traditional (and more primitive) method of mining involves tank or heap leaching whereby the ore-containing soil is excavated and put into a heap. A solution is passed through which elutes the REEs from the heaped soil. The REE-bearing solution is collected, and the REEs precipitated and recovered using an acid solution. The Chinese Government has now banned this type of mining method. The modern method uses in-situ leaching whereby an electrolyte solution is pumped directly and allowed to permeate into the ore body underground. The solution flows downwards permeating the rocks and eluting the REEs along the way. The REE-rich solution is drained and collected at the bottom. After removing the impurities, the REEs are precipitated by addition of a precipitating agent (e.g. oxalic acid) and roasted to produce a rare earth mixture containing over 92% REO.

Table 1 Prices of REE Metals / Oxides (as of 27th May 2019)

STATE	NO. OF SAMPLES ANALYSED	RANGE OF TOTAL REEs (TREEs) ppm	RANGE OF TOTAL LIGHT REEs (TLREE) ppm	RANGE OF TOTAL HEAVY REEs (THREE) ppm	NO. OF SAMPLES (THREEs) >50 - 100 ppm	NO. OF SAMPLES (THREEs) >100 ppm	NOTES
TERENGGANU	15	38.76 – 6,967.5	34.1 – 6,835	4.66 - 132.5	3	1	Granit Jerangau **(1)** Granit Air Putih**(1)** Andesit**(2)**
PAHANG	15	57 – 1,143.2	32.1 - 739	11.6 - 404.2		1	Granit Bukit Tinggi**(1)**
N. SEMBILAN	8	152.3 - 789	137.2 - 666	12.4 - 123	3	2	Granit Semenyih **(4)** Granit Beroga**(1)**
PERAK	22	39.9 - 985	30.3 - 828	7.9 - 157	1	2	Granit Banjaran Besar**(2)** Granit Bintang**(1)**
TOTAL	**60**				**7**	**6**	

1.6.3 RE minerals and REEs in marine sediments

Malaysia's territorial waters, especially in the west coast, receive a considerable amount of sediments from rivers draining granitic areas. Although not quite the same as deep-sea mud, it may be worthwhile to examine the offshore samples already collected from previous other studies for any signs of REE mineralisation.

The occurrences of RE minerals and REEs in marine sediments can be categorised into two types based on location.

Near-shore sediments

The first category of occurrence is along the near-shore areas including the continental shelf where the sediment is mainly of terrigenous origin, i.e. from the land which has been eroded and the sediments transported by rivers into the sea. This includes the erosion of granitic mounts which were previously exposed when the sea level was lower and subsequently submerged when the sea level rose. The RE in the near-shore sediments occurs mainly as minerals. The concentration of RE minerals depends very much on the provenance of the rivers bringing in the sediments.

Marine sediment surveys have been carried out by JMG as well as several other parties along the eastern and western seaboard of Peninsular Malaysia and in the coastal areas of Sabah and Sarawak.

The results of the surveys show that xenotime and monazite do occur in the marine sediments, but the concentrations are low and presently not of economic interest. Nevertheless, there are places where the xenotime contents reach up to 18% of the total heavy mineral assemblage.

Off-shore mining of tin has been carried out off the coast of Perak, and mineable concentrations of tin have been located off the coast of Melaka. Although the results of the surveys carried out so far show the contents of xenotime and monazite are presently not of economic interest, it would be worthwhile to review the results to evaluate the possibility of xenotime and monazite being mined together with tin, gold and other economic minerals. Marine surveys are generally expensive, and follow-up marine surveys should be carried out only in areas where there are clear indications of potentials.

International Seabed

Thus far, no mining of minerals from international seabed has yet been undertaken. However, under the United Nations Convention on the Law of the Sea (UNCLOS), countries are allowed to apply for "acreage" in the "Area" for exploration and exploitation of seabed minerals following the terms and conditions laid out by the International Sea-Bed Authority (ISBA). Several countries, including Russia, South Korea, India and more recently Singapore as well as several consortia, have applied for such exploration rights and some of them are already undertaking such activities in the Pacific and Indian Oceans.

It is felt that the Malaysian Government should also bid for such rights as well. The Maritime Institute of Malaysia (MIMA) is presently looking into the policy matter of Malaysia's participation in international seabed mining. However, in terms of technical and scientific matters, JMG, which has a strong marine geology division, should be involved. This is a strategic decision which Malaysia has to make and take action in a timely manner if it does not want to be left behind.

1.7 Policy on RE Mining in Malaysia

As highlighted in the ASM Blueprint, the importance of the mining sector is spelt out in the Second National Mineral Policy, launched in January 2009, which is to enhance the contribution of the mineral sector to the socio-economic development of the nation through the efficient, responsible and sustainable development as well as the optimum utilisation of mineral resources. The industry's potential as estimated by the Ministry of Natural Resources and the Environment was worth over RM4 billion in 2010. Modern mining is an industry that involves the exploration for and removal of minerals from the earth, economically and with minimum damage to the environment. Although RE mineral mining is not specifically mentioned, the Policy's Thrust 1 (Expansion of the Mineral Sector) nevertheless recognised the importance of the mineral/mining sector to the national economy and called for its expansion.

If RE minerals (and its mining) are considered essential and a strategic commodity to the development of high-technology industries in Malaysia, it is apparent that a specific policy for REs may need to be developed so that the exploration and development of this commodity can be sustainably undertaken for the nation's well-being and benefit.

1.8 Impact of a Revitalised RE Mineral Industry in Malaysia

For now, and conceivably for decades to come, RE elements are and will be an essential part of all sorts of technologies and also a host of everyday consumer electronics. As the key components in the latest generation of technologies, demand for these REEs is expected to grow rapidly in the years to come. Guaranteeing a supply of these elements is a key to ensuring that a broad range of industries stays alive and competitive.

Ensuring the security of supply of the critical RE raw material for the domestic high technology and green technology industries would be less of an issue and the country would not be so vulnerable to the vagaries of the global RE raw material supply chain. In addition to the strategic issues, the income of the nation will be lifted through an increase in export of RE minerals and downstream products and also through savings in foreign exchange as a result of import substitution.

The impact of a revitalised upstream RE industry extends beyond the mining and processing of minerals and ores. Numerous sectors will be benefitted, such as the engineering and foundry sectors that supply the plant and machinery, the mineral traders, the logistics and transport companies. The most important of all, new employment opportunities will be generated. These will contribute significantly towards helping the nation to develop its high technology industries and to reach the high-income status.

1.9 Possible Threats and Challenges of a RE Mineral Industry in Malaysia

Any industry, whether in the agricultural, mining, manufacturing, housing etc. sectors, whether sited in Malaysia or anywhere in the world, has its own specific threats and challenges. The threats of having a particular industry sited in Malaysia would need to be weighed against the challenges of not having that industry here in Malaysia. If the threats outweigh the challenges, the industry can still be welcome in Malaysia with appropriate laws and regulations to ensure that the health of the workers and the environment are not affected or endangered. If the challenges outweigh the threats, it is clear that the industry can be sited here, with the necessary laws and regulations, nevertheless in place.

The challenges could be in selecting a suitable locality of siting the industry(s), the necessary manpower (both skilled and semi-skilled), the raw materials required, and the market for the industry's products.

A greater challenge would be to ensuring that the industry has the full ecosystem available in Malaysia, where the initial raw products are processed and further processed into value-added high-end downstream products.

REs are a classic example of an industry where the challenges outweigh the threats. In the full ecosystem involving REs, it starts with the mining and initial processing at the mine site, to cracking and purification into the specific RE Oxides (of more than 99% purity), the preparation of RE metals from these oxides, and then to RE alloys from these RE metals. It is the alloys, the most valuable of the RE products, that go into the manufacture of magnets, batteries, fluid cracking and automotive catalysts, and phosphors, among others. The economic return of the full ecosystem is immense, as outlined clearly in the ASM Blueprint, contributing in no small measure to the nation's GDP.

1.10.1 Possible Threats

What are the possible threats in having the RE mineral industry in Malaysia? If the full ecosystem of an RE mineral industry is considered, that is, from the upstream sector of mining the resource (as highlighted in Section 1.6) to the midstream sector (beginning with the cracking process and the separation and purification process, where the RE is recovered from the mineral in the form of mixed light and heavy RE-carbonate compounds to the downstream sector (using various chemical and /or electro-chemical processes to separate the individual RE metals and from these metals, RE alloys are manufactured), there will inevitably be different waste products produced, depending on the stage of the processing (whether it is upstream or mid-stream or downstream). It is strongly believed that with the existing regulatory framework in place and with each sector having its own circular economy (where the wastes of the process become the raw materials necessary for the next process until no wastes remain); all wastes can be managed sustainably.

The assumption here is that all three stages of the full RE ecosystem become a reality in this country for Malaysia to be on its way to truly becoming a high-tech industrial nation.

1.10.2 Possible Challenges

Two major challenges are identified as follows:

(i) Availability of international/Malaysian investors to invest in the three stages of the ecosystem

(ii) Availability of skilled and semi-skilled Malaysians to man the various plants

Investors

It is clear that for the full RE industry to take off here in Malaysia, there must be international and / or Malaysian investors willing to invest in Malaysia, knowing that the Government will be fully supportive of their interest in investing here. The Government, on its part, has always been welcoming of high-tech industries to Malaysia with MIDA playing a very positive role in this. Investors know of the first-class infrastructure, the market economy practised by Malaysia and the investor-friendly policies and regulations in place.

Skilled and semi-skilled Malaysians

Malaysian has an ample supply of skilled and semi-skilled management and technical personnel. Lynas is an example of an Australian investor who was able to find the necessary skilled and semi-skilled personnel to man its operations in Kuantan.

The threats and challenges will further be addressed in Chapter 5.

2.0 PROSPECT OF REE IN MALAYSIA

Before the year 2000, the study conducted by the Geological Survey Department (JPK) was focused on the occurrence of monazite and xenotime minerals, which were the amangs, the by-product from the tin ore mining. Intensive REE study by the Department of Mineral and Geoscience (JMG) in Malaysia was only commenced in 2014 with collaboration and funded by ASM. The area of interest is on HREE potential from ion adsorption clay deposit derived from the weathering of alkaline and tin-bearing granites existed in Peninsular Malaysia. From this study, some potential areas in Terengganu, West Pahang, Perak and Negeri Sembilan were identified for follow-up survey.

The reconnaissance survey was continued in the 11th. Malaysia Plan using the department's development fund where the scope of the study was expanded, including the LREE and Scandium (Sc). Recent studies have discovered that some areas in Kelantan, Pahang, Johor, Sarawak and Kedah have the potential for follow-up survey where most of the samples analysed show the total REE (TREE) exceeding 300 ppm.

2.1 Deposit resources in Malaysia

From current JMG survey, there are several potential RE resources can be exploited in Malaysia, such as:

a) RE minerals – placer RE minerals deposit associated with tin ores such as monazite, xenotime and zircon
b) Weathered soils of alkali granite in Kelantan, Pahang and Johor
c) The weathered granite associated with tin-tungsten mineralization in Kedah, Perak, Negeri Sembilan, Terengganu and Johor
d) Weathered soil related to bauxite mineralization in Sarawak
e) The terra rossa soil resulting from limestone weathering in Pahang and Kedah
f) Silty clay deposited in the Malaysian coastal environment
g) Weathered soil from ultrabasic rock in Sabah (for Sc)

2.2 REE Abstraction in Malaysia

It was initially reported that there was an REE abstraction site in Tanah Merah, Kelantan, which is still in the legal process of application to obtain a mining license to operate in Kelantan. This site is for the extraction of REE from the ion adsorption clay types.

3.0 IMPORTANCE OF THE LYNAS ADVANCED MATERIAL PLANT (LAMP)

As mentioned in Chapter 1, with Lynas in Malaysia, this country is now the only country outside of China to have an RE processing and cracking plant. Malaysia can and should take advantage by mining and processing its own RE-bearing deposits with the possibility of Lynas producing high-purity Light and Heavy Rare Earth Oxides for further downstream processing and REE metal/alloy manufacturing and then to fabricating high-value magnets and other products locally if investors take up MIDA's challenge.

3.1 Economic Impact

From its Annual Reports, it is abundantly clear that, since 2008, Lynas had contributed RM2.6 billion in Foreign Direct Investment (FDI). Its capitalintensive and state-of-the-art plant resulted in further investment by local suppliers of about RM300 million.

In 2018, Lynas had contributed more than RM969 million to Malaysia's GDP, creating 1,016 direct jobs; of which 98% comprise locals from mainly Pahang and Terengganu. In that year too, Lynas paid about RM4.3 million in taxes to the local and Federal Government. Other impacts include increasing net currency inflow, skilling up employees through training with technical processing know-how, conducting CSR activities and potentially reducing import of Kieserite (a magnesium sulphate commodity used as a fertiliser in magnesium-deficient soils, especially in oil palm estates, and which Malaysia, in 2018, imported over one million tonnes of gypsum material at the cost of USD$31,061,000 (RM128 million) (Statistics Department, Malaysia). Lynas produces this material as a waste product from its Neutralisation Underflow Stream (NUF). It is radioactive free.

With the rise of advanced technologies requiring RE in the form of magnets, batteries and automotive catalysts, the demand for RE is growing globally. Malaysia is now the second-largest producer of RE globally, producing some 11% of global production, after China. This is mainly due to China implementing a policy to reduce production and limit the export of RE.

If Malaysia decides to move forward on jump-starting the complete ecosystem of the RE-based downstream-midstream-upstream industries in existing industrial estates, the spin-over investment is expected to run into billions of Ringgit Malaysia, and creating demand for skilled and semi-skilled workers. Thus, it is vital to invite international investors (with the necessary funds and technologies) to invest in a nation where the political, economic, policy and regulatory environment is clear and predictable.

3.2 Environmental Impact

3.2.1 Lynas Ore Concentrates Heavy Metal Analysis

In an analysis of the Mount Weld, the metal contents of the concentrates RE-bearing ore concentrates are shown in Table 3.

Table 3 Results on a Sample of the Lynas Sludge Concentrates

No.	Parameter	Method Ref.	Unit	Result	TTLC*
1.	Antimony as Sb	USEPA 6010B	mg/Kg	ND (<2.00)	500
2.	Arsenic as As	USEPA 6010B	mg/Kg	ND (<10.0)	500
3.	Barium as Ba	USEPA 6010B	mg/Kg	1721	10000
4.	Beryllium as Be	USEPA 6010B	mg/Kg	ND (<0.50)	75
5.	Cadmium as Cd	USEPA 6010B	mg/Kg	ND (<1.0)	100
6.	Chromium as Cr	USEPA 6010B	mg/Kg	14.7	2500
7.	Chromium Hexavalent as Cr6+	APHA 3500-CR B	mg/Kg	ND (<0.005)	500
8.	Cobalt as Co	USEPA 6010B	mg/Kg	10.4	8000
9.	Copper as Cu	USEPA 6010B	mg/Kg	109	2500
10.	Lead as Pb	USEPA 6010B	mg/Kg	639	1000
11.	Mercury as Hg	USEPA 7471B	mg/Kg	0.19	20
12.	Molybdenum as Mo	USEPA 6010B	mg/Kg	34	3500
13.	Nickel as Ni	USEPA 6010B	mg/Kg	8.06	2000
14.	Selenium as Se	USEPA 6010B	mg/Kg	ND (<10.0)	100
15.	Silver as Ag	USEPA 6010B	mg/Kg	ND (<15.0)	500
16.	Thallium as Tl	USEPA 6010B	mg/Kg	ND (<1.50)	700
17.	Vanadium as V	USEPA 6010B	mg/Kg	4.98	2400
18.	Zinc as Zn	USEPA 6010B	mg/Kg	624.25	5000

* TTLC – Total Threshold Limit Concentration; ND – Not detectable
Source: Permulab Sdn Bhd (from Lynas)

From the analytical results, as determined by an independent laboratory, it is clear that the heavy metal contents in the ore concentrate from the Lynas mine at Mount Weld, Australia are all below the Total Threshold Limit Concentration (TTLC). The high nickel reported in groundwater could not be from the feed material of Lynas.

3.2.2 Waste products

The processing of the RE concentrates results in three waste products being produced. These are the:

(i) Flue Gas Desulphurisation (FGD) Stream
(ii) Neutralisation Underflow (NUF) Stream
(iii) Water Leach Purification (WLP) Stream

(i) Flue Gas Desulphurisation (FGD) Stream

Flue Gas Desulphurisation (FGD) Stream, or Waste Gas Treatment Streams, consists predominantly of gypsum (calcium sulphate). This Stream could be sold to the Malaysian plasterboard market or the cement industry for the manufacture of blended cement and agricultural markets as a calcium and sulphur nutrient and the treatment of clay soils. The radioactivity concentration, according to IAEA, is 0.04 Bq/gm Th-232 and 0.003 Bq/gm U-238, both concentrations considered very low.

(ii) Neutralisation Underflow (NUF) Stream

NUF (containing high levels of magnesium, aluminum and calcium sulphate – essentially "gypsum") could be sold in the local agricultural market instead of importing kieserite, a soil fertiliser/ameliorant. According to the IAEA, the radioactivity concentration in NUF is below 0.02 Bq/gm for Th-232 and 0.006 Bq/gm for U-238. Both concentrations considered as being below the AELB limits of 1 Bq/gm for both Th and U and thus considered to be non-toxic, non-carcinogenic and non-radioactive.

(iii) Water Leach Purification (WLP) Stream

The WLP Stream also contains relatively high levels of the nutrients phosphorus and magnesium which have potential agricultural markets. The radioactivity concentration, according to IAEA, is 6 Bq/gm Th-232 and 0.2 Bq/gm U-238. The Th concentration recorded is above the AELB limit of 1 Bq/gm and has given rise to concern among sections of the public.

3.3 The issue of Waste Management

As mentioned above, the processing/cracking of rare earth (lanthanide) concentrates at the Lynas Plant in Gebeng produces two solid gypsum residues as by-products. These are the Neutralisation Underflow Residue (NUF) and the Water Leached Purification Residue (WLP). It is these two by-products that are at the core of the waste problem facing Lynas.

Although NUF is considered to be non-toxic, non-carcinogenic and non-radioactive, it is however classified as scheduled waste gypsum under SW 205 by DOE due to it being produced by the chemical industry. Its magnesium-rich properties and other chemical properties can be used to condition poor agricultural soil and to rejuvenate and rehabilitate unproductive and depleted land. NUF is neutralised with lime to produce synthetic gypsum.

The Water Leach Purification (WLP) is product water obtained after cracking which dissolves much of the REs and some of the iron as soluble sulphates. After the leaching process, the liquid is partially neutralised with magnesium oxide to facilitate separation of the soluble REs occurring as sulphates from iron, aluminum and phosphate, which precipitate. The combined insoluble solid residue from the water leach and precipitates from the magnesium oxide neutralisation step is known as WLP.

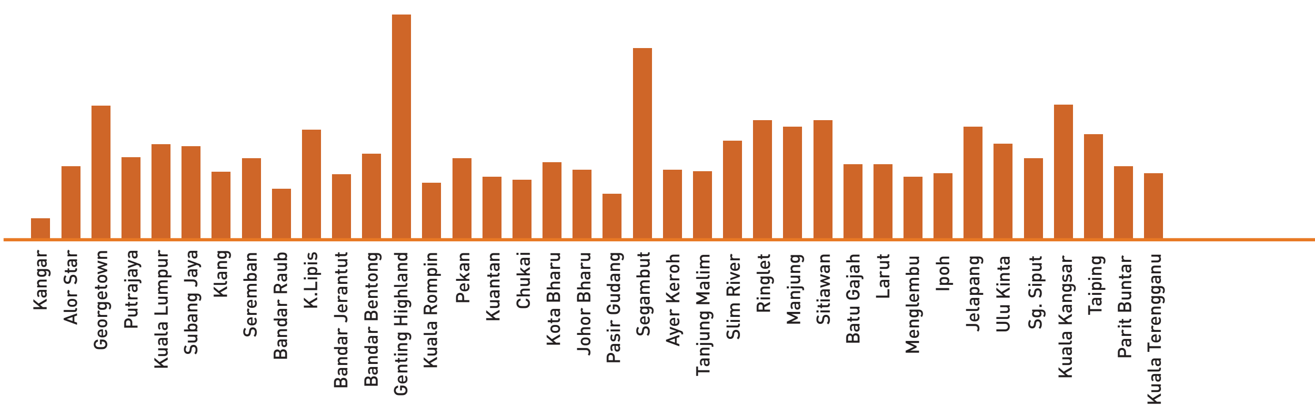
The WLP residue, although classified as radioactive material, has the same radioactivity level as the feedstock material used in the LAMP process (about 6 Bq/g of Th). This material is classified as very low-level radioactive material. The LAMP operation does not enhance or alter the natural radioactivity.

It is relevant to point out here that in three studies on radioactivity background levels undertaken in the Kinta Valley and around the Lynas plant, the results are revealing. In the Kinta Valley study undertaken by a student from UTM in 2007, a total of 128 soil samples collected in the Kinta district between 2003 and 2005 were analysed for the activities of the naturally occurring radionuclides, gross alpha and gross beta activities. The activity concentrations of 238U, 232Th and 40K were analysed by using a HPGe detector. The ranges were 12 – 426 Bq kg-1 for 238U (equivalent to 0.012 Bq/gm) and 19 – 1377 Bq kg-1 for 232Th (equivalent to 0.019 – 1.377 Bq/gm). These are background values, and they show the highest Th value exceeding the concentration in the Act.

In the second study undertaken by AELB from September 2012 to May 2013, AELB reported that the average reading of the background radiation was below the mandated level of 0.5 μSv/hour. There was also no increase in the background radiation level in July 2013 at the Lynas plant site. The AELB study also showed the background radiation levels in townships in Peninsular Malaysia (Figure 2).

In the third study undertaken by research officers from the Malaysian Nuclear Agency, Yii and Zal U'yun (2016), few samples were collected from a total of 31 stations randomly selected and established within 3 km radius surrounding the plant. The samples were where the topsoil (< 5cm depth) obtained randomly from a metre square area of each station. The sampling process was repeated at the same monitoring station with an interval of approximately two-three months between May 2014 until November 2014.

Average Dose of Radiation at Cities in Peninsular Malaysia (micro Sv/j) surveyed in November 2012 to May 2013



The results showed that the natural radioactivity in the surface soil from the vicinity of Lynas RE plant in Kuantan, Pahang, gave values of activity of 238U from 8.7 to 80.5 Bq/kg (mean 36.9 Bq/kg) and for 232Th, it ranged from 6.2 to 121.5 Bq/kg (mean 58.2 Bq/kg). These researchers concluded that the mean dose equivalent received by an individual at the vicinity area (outdoor) of Lynas plant was estimated to be 82.0 μSv/yr, which is far below the annual dose limit of 1,000 μSv/yr for the general public as stipulated in the national Atomic Energy Licensing Act 304 (1984).

So far, there is no concrete data to prove any significant health impact in recent years. In order to put to rest health concerns affecting the populace staying around the plant due to long-term exposure to radioactivity from the Lynas plant, ASM proposes to initiate and lead a health monitoring and baseline studies to make sure health and safety of nearby residents are not affected.

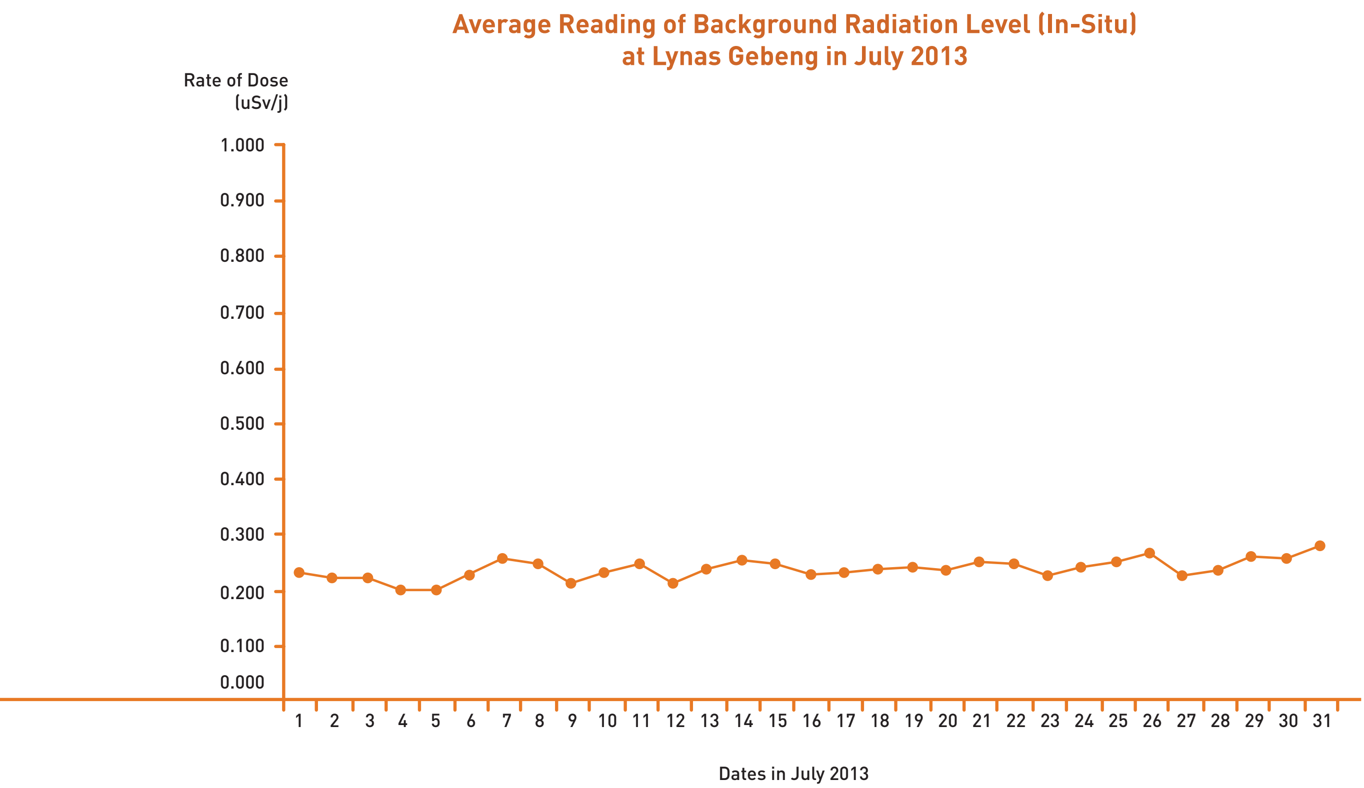


Figure 2 Comparison of the Background Radiation Dosage of Lynas and the Selected Townships for July 2013
Source: AELB (Monitoring Status of the Lynas Project, presented in September, 2013)

WLP is also iron phosphogypsum with chemical properties that compliment NUF for the same agricultural purposes. The formulation of soil conditioners, known as CondiSoil, using WLP, NUF and inert filler materials, has been proven through extensive research to be nonradioactive, non-toxic, and non-carcinogenic. The AELB has acknowledged that the formulated soil conditioner is not a radioactive material. During product development and commercialisation, Lynas had reported to have adhered strictly to all the guidelines provided by the regulatory authorities (including the DOE and the AELB) in ensuring that the products developed are both safe for people and safe for the environment.

CondiSoil was developed under the Lynas CondiSoil Project, being part of the Lynas plan for Special Management of its scheduled waste under Regulation 7(1) Environmental Quality (Scheduled Waste) Regulations 2005. The CondiSoil Project is part of Lynas's recovery effort to safely commercialise residues generated.

Furthermore, in a study published by Elsevier's Science of the Total Environment Vol. 652 (2019) 573–582, a study, undertaken jointly by UPM, UKM and UMS, was conducted in an oil palm plantation in Peninsular Malaysia to elucidate the effects of applying Magnesium Rich Synthetic Gypsum (MRSG), a by-product of a chemical plant (from Lynas), on the chemical properties of soil, the uptake of heavy metals by the palm trees, the oil quality and its impact on the surrounding environment.

The results showed that MRSG application onto soil cropped to oil palm could bring positive impact in terms of soil chemical properties and oil palm production. The quality of the oil was not significantly affected by the continuous MRSG application as shown by the low heavy metals and trace elements of concern content (Cu: 0.062 mg/kg; Fe: 2.10 mg/kg; Mn: 1.93 mg/kg; Pb: 0.006 mg/kg; Zn: 0.103 mg/kg; Cr: 0.354 mg/kg; Ni: 0.037 mg/kg). From the I-geochem index, the soil was found to have values ranging from –3.81 to –1.03, which is considered as uncontaminated. Further, its application did not result in negative impact on the surrounding environment; hence, the quality of the soil and surface water in the plantation and/or the surrounding area remained intact. Phytotoxic elements in the oil palm tissue (As: 0.12mg/kg; Se: 0.05mg/kg; Zn: 1.48mg/kg; Ce: 0.47 mg/kg; La: 0.26 mg/kg; Sr: 3.03 mg/kg) and cytotoxic elements in the oil were below the acceptable limit.

Based on the results of the Environmental Monitoring out during the period of the study, it was concluded that application of the by-product of the chemical plant as a source of Mg to enhance soil fertility in the oil palm plantation was considered safe and sustainable. The effects of applying MRSG and Chinese kieserite were almost similar. So, MRSG can be used as a possible source of Mg to replace Chinese kieserite for oil palm production on the Ultisols in Peninsular Malaysia.

Although Lynas is required to plan and site a permanent disposal facility (PDF) as an additional assurance in dealing with Lynas residues, Lynas is confident that the success of its commercialisation programme, from similar studies conducted locally, has reduced the likelihood that a PDF will be required. However, the Government has now requested for Lynas to stop doing research on the use of its radioactive wastes as a soil-improvement conditioner.

3.4 Summary of Lynas Operations Evaluation Committee Report 2018

There is confusion among Malaysians on radiation impact between factories that extract RE that contains Naturally Occurring Radioactive Material (NORM) and nuclear plant. In general, LAMP complied with the safety, health and environment standards in accordance with the provisions of law. LAMP has conducted a study for the recycling of both WLP and NUF waste residues. However, the commercialisation of products has yet to be implemented because it requires further research. Based on the report, the employee's exposure to radiation and non-radiation hazards was below the level allowed during LAMP operation.

The Committee recommends LAMP to immediately provide and establish a safe storage site for NUF residues. LAMP should immediately identify the location and build a permanent disposal facility (PDF) of the WLP residue. All research on the recycling of NUF residue without involving WLP residue can be continued. Independent Research and Development (R&D) Committee shall be established to coordinates, evaluates, determines and monitors the studies to ensure that the research conducted is free of any conflict of interest from LAMP. 1% of LAMP's gross sales annually for R&D purposes will be imposed as a condition of the license, to be submitted for operation by the independent R&D Committee. The Government should look at the development of RE industry holistically to create an appropriate ecosystem supported by legislation, governance, education, human capital development, R&D and ethics that meet the latest international standards to achieve sustainable development and investment.

4.0 THE OPPORTUNITY FOR MALAYSIA DOWNSTREAM OF RE INDUSTRY

As stated in Chapter 1, the Chinese domestic market for RE-enabled devices is growing more rapidly than the global market. The Chinese have made it clear that their domestic needs will come first. China is the only producer today of terbium, dysprosium, and yttrium. If these materials are cut off then there can be no non-Chinese domestic total supply chain anywhere else unless non-Chinese heavy rare-earth production, refining, and fabricating are given immediate priority.

Malaysia is uniquely situated to take advantage of this dilemma. Malaysia has been an RE producer and exporter for a long time. Lynas now has the largest single light RE separation facility in the world, and that facility can be supplied indefinitely from Australian resources. Malaysia has good sources of heavy REs and the ability to attract specialised refining and fabricating vendors to cover the entire spectrum of rare earth enabled products.

4.1 The Importance of Processing Malaysian RE Oxides - Exploiting and Value-Adding to the Existing LAMP Technology

The LAMP in Gebeng, Kuantan, chemically processes the rare earth concentrates containing about 40% RE oxides with the final products containing 95% - 99.99% purity refined RE oxides. These are then exported to Lynas' customers in Japan, China and France where plants further process the REOs to metals, alloys and phosphors.

A scenario worth exploring is the possibility of having Lynas to process Malaysian RE oxides from the ion-adsorption clays. The advantage of this is that ion-adsorption clays have been reported to contain very low amounts of thorium and therefore would not be considered hazardous. Lynas would probably expect consistent supplies from the Malaysian miner (that is if the miner has not committed himself to sell his product overseas). As both the Australian concentrates and the Malaysian ion-adsorption clays' are REOs, Lynas should not have any technical problems chemically processing both.

As mentioned in Chapter 1, to support a total domestic supply chain for an RE industry will require sources of the light RE and of the heavy RE along with chemical engineering facilities capable of separating large quantities of light RE from each other and also capable of separating much smaller quantities of heavy RE from each other. In addition, facilities will be needed to produce pure rare earth metals and alloys from the separated chemical forms of all of the RE. The next step will be facilities to produce rare earth permanent magnet alloys, lasing chemicals, and phosphor chemicals. Finally, manufacturers of RE enabled devices will be needed to fabricate RE permanent magnets, lasers, and phosphors for use in consumer, industrial, and military end-use products".

What are the potential economic returns to Malaysia if the nation moves forward with downstream RE industries in the digital era? In the processing and cracking of the RE concentrates in Malaysia, Lynas had invested USD$800 million, resulting in the creation of 650 direct job opportunities for Malaysians and an annual sales amounting to USD$360 million.

With the purified RE oxides Lynas produces and after the conversion of these oxides to RE metals and alloys (currently being undertaken in Japan and China), these alloys can be used to make RE-based magnets (of neodymium-iron-boron composition) for use in electric vehicles, for example. An investment of USD$150 million in Malaysia can provide direct job opportunities to around 300 Malaysians and an annual sales amounting to USD$150 million.

In the case of investments in RE-based electric motors, an investment of USD$300 million would lead to the creation of 500 direct job opportunities and an annual sales amounting to USD$600 million.

Therefore, it is not sufficient that Lynas only process the Malaysian REOs. Malaysia needs to have the necessary chemical engineering facilities capable of separating large quantities of light REs from each otherand also capable of separating much smaller quantities of heavy REs from each other, and facilities to produce pure RE metals and alloys from the separated chemical forms of all of the REs. Further, facilities to produce RE permanent magnet alloys, lasing chemicals, and phosphor chemicals will also be needed. Finally, manufacturers of RE enabled devices will be needed to fabricate RE permanent magnets, lasers, and phosphors for use in consumer, industrial, and military end-use products.

MIDA in 2013 had in fact identified 10 high technology, capital intensive and knowledge-driven industries, namely, alternate energy sources, biotechnology, advanced materials, advanced electronics, optics and photonics, petrochemicals, pharmaceuticals, medical devices, ICT, and aerospace. All of these industries, in one way or another, use rare-earth-based products in their processes.

MIDA had also identified for the information of national and international investors the investment opportunities in downstream rare earth products in their Rare Earths Ecosystem (Figure 3).

RARE EARTH ECOSYSTEM

Value Chain	Rare Earth (RE) Metal Oxides	RE Metal	RE Magnets Blocks	RE Magnet	RE Products	Application & End Users
TARGETED COMPANIES	*Cerium Carbonate*			Voice Coil Motors (VCM)	Hard Disk Drives (HDD)	Computers
	Lanthanum Carbonate			Motor magnets	Motor for Electric & Hybrid Cars	Hybrid Cars
	Lanthanum Cerium Carbonate	*Metal Lanthanum*	*Neodymium Magnet Blocks*	Magnets for Other Applications: ABS Systems Airbags	ABS Systems for cars, Airbags for Cars	Hand phones, MP3, Home, Entertainment, Other AV Systems
	Neodymium Proa-seodymium Oxide					
	SEG + Heavy rare earth			General Applications	Amplifiers Sound System	
Ecosystem	R&D Companies Universities	**Equipment Manufacturer** **Services** *Logistics, warehousing, Retails, Services & Repairs*		**Policy Framework** *e.g. Atomic Energy Licensing Regulations 2011, Radiation Protection (Licensing) Regulations 1986*		

Figure 3 MIDA's Rare Earths Ecosystem, Source: MIDA (2013)

5.0 MAJOR ISSUES FACED IN RE MINING/PROCESSING

In the pursuit of any modern technologies, the issue of waste management will inevitably arise. With proper and effective applications of science and technologies in waste management, these waste issues can be overcome. More so with mining and processing of the mined products. REs have been mined and partially processed in Malaysia as a by-product of tin mining where the REs containing monazite and xenotime minerals were separated from the mined tin concentrates through magnetic and electrostatic separation. It is this generally low-cost monazite and xenotime concentrates that were initially sold to Japan and the USA for REs separation until Japan set up the Asian Rare Earth plant near Ipoh to do the separation locally. However, the thorium and uranium contents occurring naturally in both the xenotime and monazite led to much public discontent against the plan, which then led to its closure. Malaysia has the potential once again to mine REs but this time from the ion-adsorption clays overlying granitoid bodies in the country. The RE from these clays are essentially radioactive free (details of the minerals and mining have already been mentioned in Chapter 1).

5.1 Possible Closing of LAMP

If Lynas is closed for its waste-related reasons in the near future, Malaysia would have lost an opportunity to migrate to high-technology industries that need high-value lanthanide-based products used in wind turbines, hybrid electric vehicles, lighting, oil cracking etc. In other advanced countries, such as South Korea, Japan, USA, France and Germany, RE-based industries contribute significantly to the nation's GDP.

Lynas had already begun R&D on its waste streams in order to see how the wastes can be used/sold as another product of the plant. A possible way is the use of the phosphate-bearing NUF and WLP wastes as soil enhancers, but the Government had recently requested Lynas to stop its research on this area.

5.2 New RE Mining

Ion-adsorption clays are the new source of RE-bearing lanthanides. The attractiveness of these clays is that they are essentially radioactive free.

In the ASM publication entitled Revitalising the Rare Earth Mineral Industry in Malaysia: A Strategic Industry (2012), the report addressed the mining of ion-adsorption clays. It stated that these clay deposits as being the largest source of heavy rare earth HREEs. Thus far, only the deposits in South China are in commercial production, but such deposits have been discovered elsewhere, for example in Laos and Vietnam. In Malaysia, in a preliminary assessment of such clay deposits, ASM had, in 2014, commissioned a study with the JMG in Peninsular Malaysia (Perak, Terengganu, Pahang and Negeri Sembilan). The results were extremely encouraging, leading to the recommendation that the Government undertake a detailed exploration on this strategic resource.

According to JMG, currently, there is a proposed mine, located in Tanah Merah, Kelantan, planned to work on ion-adsorption clays. This mine has yet to obtain a mining license from JMG.

5.3 Governance (Policy)

Although the Second National Mineral Policy (2009) was launched to enhance the contribution of the mineral sector to the socio-economic development of the nation through the efficient, responsible and sustainable development as well as the optimum utilisation of mineral resources, RE mineral mining is not specifically mentioned.

As highlighted in Chapter 1, if RE minerals (and its mining) are considered essential and a strategic commodity to the development of high-technology industries in Malaysia, it is apparent to develop a specific policy for RE so that the exploration and development of this commodity can be sustainably undertaken for the nation's well-being and benefit.

5.4 Human Capital Development to Satisfying RE-based Industry Needs

ASM publication entitled A Blueprint for the Establishment of Rare Earths Industries in Malaysia – A New Source of Economic Growth (2014) pointed out on the difficulty to ascertaining Human Capital Development at the university level for RE upstream, midstream and downstream activities as the RE mining industry is still at the nascent stage in Malaysia. Malaysia is less fortunate as the engineers produced by Malaysian universities are buyers, users and maintenance of equipment and very few realise that some of the products they use contain RE elements. Therefore, the Blueprint proposed that Malaysia needs to develop a Rare Earth Human Capital Strategy focusing on demand creation in RE innovative product innovation for Malaysian graduate engineers to have the necessary innovative capacity and capabilities.

For demand creation to be able to ascertain the human capital requirements for RE product innovation, the Blueprint further proposed that Malaysia adopts the following Strategic Imperatives:

- Re-strategise its FDI policies and to attract REE product development and innovation companies into Malaysia
- Make REEs resources as strategic and any disruption in the supply will hamper the FDI initiative
- Attract electric and hybrid car manufacturers to invest in Malaysia as the REE components are substantial.
- Develop an innovative capacity to create REE product innovations in Malaysia through international collaboration with the Centre of Excellence.
- Designate RE research in universities for downstream, midstream and upstream in Malaysia similar to Korea and Japan (with the necessary funding by relevant ministries).

The demand creation Strategic Imperatives would provide sustainable human capital for RE innovative product development, and at the same time, Malaysia will be able to attract new investments in rare earth industry into Malaysia.

The Blueprint also proposed the downstream REE product innovations be designated to the Malaysian Technical University Network (MTUN) to have the necessary infrastructure to build capacity and future knowledge in RE applications and innovations.

In the upstream sector, as the RE mining industry involves risks, the Blueprint identified the need for rigorous safety features typically deployed in harsh working environments. Therefore, Automation is needed to improve Occupational Health and Safety in the mining industry. Skills in Automation, such as Automation Technician, Mechatronics Engineer and Operations Optimization Manager, are required. In this aspect, the Blueprint proposed that UTeM provides comprehensive TAFE-delivered Vocational Education and Training (TVET) courses in Automation for the mining industry.

For the upstream (mining) and midstream (extraction and processing), Malaysia has limited human resources with some courses available at local universities. However, there is a gap if compared to Australian universities. There is a need to narrow the gap in terms of the courses offered, and it is recommended that local universities collaborate with Australian universities, especially with University of Queensland, University of Western Australia, Curtin University and Murdoch University.

Malaysia has the possibility of having reserves of HREE-bearing minerals where xenotime, a by-product of tin mining, can still be found in places like Lahat in the Kinta Valley, Perak. In addition, while studies have indicated that ion-adsorption clays are found in South-eastern China, Malaysia's geological footprint indicates that ion-adsorption clays may also occur in Perak, Selangor, and Negeri Sembilan. Therefore, it is proposed that exploration using the latest technologies to determine the Malaysian Rare Earth reserves is conducted with great urgency.

In order to ensure that RE is of strategic importance and can become the engine of a new economic growth area for Malaysia, the Blueprint proposed the setting up of the Malaysian Rare Earth Research Institute for upstream, midstream and downstream research activities to develop research competences and expertise.

The above proposal can only be realised with a high degree of success with political will and financial resources behind such an ambitious programme for demand creation, exploration and the necessary capabilities for Malaysian to become innovative product developers in RE applications.

At the Vocational level, to revitalise REs processing and mining-related industries in Malaysia, vocational-skilled individuals or sub-professionals need to be properly developed because of the shortage of experienced and skilled workers.

Some of the vocational skills needed are specific to mining and RE related industry, but most competencies required are fortunately common with others. Existing polytechnics and training institutes are able to churn out skilled individuals needed.

These established polytechnics and institutes can also be extended to offer mining-related courses in the future. States like Pahang and Perak, where most mining workers in Malaysia are employed currently, are top candidates whose institutes can be upgraded.

Sighted education and training models in Western Australia with its established mining industries can be adopted on a smaller scale in Malaysia. Collaboration with Australian Government and training organisations may jump-start our efforts.

5.5 Research and Development on RE

A Blueprint for the Establishment of Rare Earths Industries in Malaysia – A New Source of Economic Growth (2014) had separated R&D activities under the sub-headings of Upstream – Mining, Mid-Stream – Separation, Cracking and Purification and Downstream – including R&D in the RE-related industries. The Blueprint had given many proposals for R&D to be conducted by local universities as well as industries.

6.0 WAY FORWARD

In a recent statement by the Atomic Energy Licensing Board (AELB) on 15th August 2019 on the six months renewal of Lynas Malaysia Sdn Bhd's operation licence, few conditions have been set. Lynas has to identify a site for its permanent storage facility (PDF) for its low-level radioactive waste. Otherwise, Lynas must find a country willing to consent to take the waste. It must be other than Australia, as the Australian Government and the Western Australia state Government have informed that they will not be accepting Lynas' radioactive Water Leach Purification (WLP) residue. Lynas has to transfer its cracking and leaching process to another country. In addition to that, all R&D activities on the WLP radioactive residue as CondiSoil for agriculture need to be terminated. Lynas needs to submit 0.5% of the gross sales annually designated for previous R&D efforts to the Government of Malaysia as additional collateral up until the cracking and leaching facility is in operation overseas. The decision was based on the recommendation made by Lynas Operation Executive Review Committee in its report on November 2018.

The RE elements have been named "The Vitamins of Modern Industry" as they are vital to many modern technologies and help to fuel global economic growth, maintain high standards of living and even used in medical equipment. In recent years, demand for REs has been increasing, particularly for use in energy efficiency and high technologies. RE may not only be capable of meeting the needs of being faster, lighter, smaller and more efficient, but it also plays an important role in developing green industries.

The move by various parties to push for the closure of the LAMP in Gebeng, ostensibly because of its radioactive wastes, is not a healthy development for Malaysia as it strives to be a regional centre for high-technology, capital intensive, knowledge-driven (MIDA, 2013) industries. MIDA had in fact had identified RE-based downstream industries in the value chain ranging from RE Metal Oxide production to RE Metal production to manufacturing RE Magnet blocks to manufacturing RE Magnets and RE Products to Applications and End Users.

Malaysia is blessed because it has the basic starting block of the full ecosystem; from the occurrence of ion-adsorption clays, containing essentially radioactive-free RE elements, to processing and cracking of the RE elements (both heavy and light as is being undertaken by Lynas) for the establishment of downstream RE-based industries.

As the country's high technology industry continues to develop and expand, a secure supply of RE raw material is critical; otherwise, the industry would be vulnerable to vagaries of the international RE supply market. The upstream and downstream of mining industries will be an advantage to us. The creation and establishment of these multi-billion dollar industries in Malaysia would augur well for the continuous development of its human capital (from mining to processing to manufacturing) as well as contributing to the national GDP.

There is no concrete data to prove any significant health impact in recent years. In order to put to rest health concerns affecting the populace staying around the plant due to long-term exposure to radioactivity from the LAMP, ASM proposes to initiate and lead a health monitoring and baseline studies funded by relevant bodies or agencies to make sure health and safety of nearby residents are not affected. The journey towards a high technology advanced nation will inevitably involve certain risks to be faced upfront, which, with the appropriate science and technology interventions, can be minimised.

Closing down LAMP will send a strong negative message to advanced nations intending to invest in high-tech high-risk high growth industries in Malaysia. Malaysia is currently the only nation globally, outside China, with an RE processing plant. The wastes (both the WLP and NUF) from Lynas have a value which can be sold as part of the circular-economy approach with the current low amount of radioactivity in the WLP to be further lowered by admixing with barren soil. Insisting that countries to take back "their" wastes can send a wrong message to these countries. They may, in return, insist Malaysia take back its palm oil, rubber and plastic lining wastes from these countries.

A well-tailored policy for sustainable RE exploration and mining including developing an environmentally -sustainable set of procedures to mine the ion-adsorption clays by KATS will be a good move, so as to enhance the regional exploration for RE in ion-adsorption clay deposits nation-wide. These ion-adsorption clay deposits are essentially radioactive-free. Mining companies in Malaysia should be encouraged to undertake the detailed exploration and mining of ion-adsorption clay deposits in Malaysia (ion-adsorption clays contain radioactive-free REs) with KATS developing strict and enforceable SOPs and guidelines to assist states in the issuance of RE mining licenses to these companies.

In addition, we can invite RE specialist companies to Malaysia to establish downstream RE industries (plants) to process high-purity RE oxides from Lynas and RE oxalates from Malaysian ion-adsorption clay deposits to produce high value-added RE metals and to higher value-added RE alloys as well as to highest value-added RE-based products such as magnets, turbines, electric vehicles, catalysts etc. The employment opportunities for high-skilled (from universities) and medium-skilled (from TVET institutions) Malaysians in these plants is immense.

7.0 CONCLUSION

The move by various parties to push for the closure of the Lynas plant in Gebeng, ostensibly because of its radioactive wastes, is not a healthy development for Malaysia as it strives to be a regional centre for high-technology, capital intensive, knowledge-driven (MIDA, 2013) industries. MIDA had in fact had identified rare earth-based downstream industries in the value chain ranging from RE Metal Oxide production to RE Metal production to manufacturing RE Magnet blocks to manufacturing RE Magnets and RE Products to Applications and End Users.

Malaysia is blessed because it has the basic starting block of the full ecosystem, that is, from the mining of ion-adsorption clays, to processing and cracking of the rare--earth elements (both heavy and light as is being undertaken by Lynas) for the establishment of rare-earth-based industries.

The creation and establishment of these multi-billion dollar industries in Malaysia would augur well for the continuous development of its human capital (from mining to processing to manufacturing) as well as contributing to the national GDP.

In summary,

There is no concrete evidence-based data to prove any significant negative health impact caused by the Lynas operations. In order to put to rest health issue concerns affecting the populace staying around the plant due to long-term exposure to radioactivity from the LAMP, ASM proposes to initiate and lead a health monitoring and baseline studies funded by relevant bodies and agencies to make sure health and safety of nearby residents are not affected.

J1

The journey towards a high-technology advanced nation will inevitably involve certain risks to be faced upfront which, with the appropriate science and technology interventions, can be minimized or neutralised.

J2

Closing down LAMP will send a strong negative message to advanced nations intending to invest in high-tech high-risk high-growth industries in Malaysia. Malaysia is currently the only nation globally, outside China, with an RE processing plant.

J3

The wastes (both the WLP and NUF) from Lynas have value which can be sold as part of the circular-economy approach with the current low amount of radioactivity in the WLP to be further lowered by admixing with barren soil.

J4

Insisting that countries take back "their" wastes can send a wrong message to these countries and these countries may in turn insist Malaysia take back its palm oil, rubber and plastic lining wastes from these countries.

J5

There is a need for KATS to develop a specific policy on RE exploration and mining, including developing an environmentally-sustainable set of strict and enforceable Standard Operating Procedures and guidelines to mine and process the ion-adsorption clays, so as to enhance the regional exploration for rare earths in ion-adsorption clay deposits nation-wide. These ion-adsorption clay deposits are essentially radioactive-free.

J6

Local mining companies in Malaysia should be encouraged to undertake the detailed exploration and mining of ion-adsorption clay deposits in with KATS assisting states through providing technical assistance on mining and processing of ion-adsorption clays as well as in the issuance of RE mining licenses to these companies.

07

International RE specialist companies should be invited to Malaysia to establish both mid-stream and down-stream RE industries (plants) to process high-purity RE oxides from Lynas and RE sulphates from Malaysian ion-adsorption clay deposits to produce high value-added RE metals and to higher value-added RE alloys as well as to highest value-added RE-based products such as magnets, turbines, electric vehicles, catalysts etc.

08

The employment opportunities for high-skilled (from universities) and medium-skilled (from TVET institutions) Malaysians in these plants is immense.

09

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