Review of the Current State of Development and the Potential for Environmental Impacts of Seabed Mining Operations

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Executive Summary

Currently, there are a range of mining operations in the shallow seabed, including diamond mining in Namibia and Tin mining in Indonesia. Due to rising demand for minerals and metals and declining land-based resources, there has been a recent surge of interest in exploration of both shallow and deep sea resources. However, there are environmental concerns with mining the seabed. Only a fraction of the deep sea has been scientifically studied to date and there have been no commercial scale mining trials so far. Nonetheless, given the nature, scale and locations of proposed seabed mining activities serious and, in some cases, widespread negative impacts on habitats and marine life can reasonably be expected.

Marine habitats which are being explored for prospective mining include hydrothermal vents (deep sea geysers) which host a unique biodiversity; seamounts (underwater mountains) which support an abundant and rich biodiversity; and manganese nodules which take millions of years to form and support sponges and other marine life. There are conservation concerns regarding the destruction of these habitats by mining, the resulting loss of biodiversity and the uncertainty that habitats and biodiversity may not recover once mining has ceased.

(i) Mineral Deposits of Commercial Interest to Mining

Manganese Nodules (MN), Cobalt-rich Crusts (CRC), and Seafloor Massive Sulphides (SMS) are the three major types of marine mineral deposits that are recognised in the world's deep seafloor environment which are the main focus of exploration and mining.

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In summary the main reserves for prospective marine mining are:

- Manganese Nodules (MN) in the Clarion Clipper Zone (CCZ) in the Pacific Ocean
- Seafloor Massive Sulphides (SMS) at hydrothermal vents particularly those off the coast of Papua New Guinea (PNG)
- Phosphates off the coast of New Zealand and Namibia
- Cobalt Rich Crusts (CRC) at seamounts worldwide with the largest deposits being in the Pacific Ocean

Many companies have been granted licenses for prospecting and mining in both territorial and international waters accounting for a total seabed area of around 1 843 350 km^2 (Hein *et al.,* 2013).

The International Seabed Authority (ISA) is an autonomous intergovernmental body established to organise, control and administer mineral resources beyond the limits of national jurisdiction. To date, the ISA has approved 17 exploration contracts. Twelve of the exploration licences are in the Clarion-Clipperton Zone in the Pacific Ocean, three are in the Central Indian Ocean and two are in the Atlantic Ocean, along the Mid-Atlantic Ridge. However, currently it is not yet technologically feasible to mine Manganese Nodules or Cobalt Rich Crusts.

Seabed mining is imminent in three regions: (1) mining of SMS deposits in the Bismark Sea within the Exclusive Economic Zone of Papua New Guinea (the Nautilus Minerals Solwara 1 Project); (2) phosphate mining off the coast of Namibia (Namphos by Union Resources Ltd and Mawarid Mining); and (3) mining of SMS deposits within the Atlantis II Basin in the Red Sea (by Diamond Fields International).

(ii) Environmental Concerns

There are many environmental concerns regarding these projects and other prospective deep sea mining activities – these are identified and discussed in this report. The habitats targeted and the probable impacts from mining may be summarised as follows:

<u>Hydrothermal vents</u> host a unique community structures with many species of animals being exclusively native to these habitats. Mining would remove thousands of vent chimneys completely, flattening the seabed. Resident animals would be killed. As part of its developments in Papua New Guinea, Nautilus plans to try and transfer animals to other sites but this is scientifically

untested and could also disturb other ecosystems. It is unknown whether habitats would recover or if animals would return if vent chimneys reformed.

Seamounts studied to date show there is an abundance of life associated with these structures, including corals and sponges and huge aggregations of fish. Seamounts have been described as underwater oases and they appear to be important habitats for migrating species. Mining in the vicinity of these structures will destroy corals and sponges which grow on the seamounts and recent studies indicate that recovery times would be in decades to centuries.

Manganese Nodules extraction would remove some of the only hard substrate on the abyssal deep sea floor resulting in habitat loss and mortality of resident animals. Manganese nodules themselves take millions of year to form so these habitats could be completely lost from large areas of seabed.

There are concerns that noise from any deep sea mining operations would travel over large distances and could negatively impact on deep diving whales and deep sea fish which use sensitive acoustic changes for communication and navigation. There are also fears that exclusion zones around mining areas in coastal waters will reduce fishing areas impacting on local people's livelihoods. Furthermore, the deep-sea has high intrinsic and potentially commercial value in the form of marine genetic resources, including perhaps the pharmaceutical basis for new treatments and therapies., There are concerns that mining may destroy genetic resources before they are even investigated.

Mining is thus certain to cause some irreversible damage and negative impacts to unique deep sea habitats. To protect marine habitats Greenpeace is calling for the implementation of a global network of Marine Reserves which would protect at least 40% of the world's oceans including particularly vulnerable areas such as seamounts, and hydrothermal vents.

(iii) Metals from Deep Sea Mining and their uses

Commercial interest in mining the deep sea is based on the a range of metals with important uses (see Table 1) and rare earth elements (used in emerging and next generation technologies). In addition there is interest in offshore phosphates for use in manufacturing fertilizer and other products.

Table 1. A summary of the uses of major metals occurring in the seabed

Element	Symbol	Uses	Comments
Manganese	Mn	Manganese is a metal with important industrial metal alloy uses	Found often in combination with iron, and in many other minerals
Nickel	Ni	Chiefly valuable for alloys, especially many superalloys, and particularly stainless steel as in chemical plants, petroleum refineries, electrical appliances, and motor vehicles.	Nickel is magnetic, and is very often accompanied by cobalt
Copper	Cu	Copper is malleable and ductile, a good conductor of heat and, when very pure, a good conductor of electricity	Minerals such as the sulphides: chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), covellite (CuS), chalcocite (Cu_2S) are sources of copper
Cobalt	Co	Used in the preparation of magnetic, wear-resistant, and high-strength alloys as in the electrical, communications, aerospace, and engine and tool manufacturing industries.	Cobalt is usually not mined alone, and tends to be produced as a by-product of nickel and copper mining activities.
Iron	Fe	Its low cost and high strength make it indispensable in engineering applications such as the construction of machinery and machine tools, automobiles, the hulls of large ships, and structural components for buildings.	Iron is the most widely used of all the metals, accounting for 95% of worldwide metal production.
Gold	Au	Used as money, a store of value and in jewellery. Pure gold is too soft for ordinary use and is typically hardened by alloying with copper or other base metals.	It is a highly sought-after precious metal and occurs as nuggets or grains in rocks.
Silver	Ag	Used in many industries the major ones being jewellery, silverware and alloys.	It has the highest electrical conductivity of any element and the highest thermal conductivity of any metal.

(iv) The Alternatives – Re-use and recovery of minerals and metals

The mining of Seafloor Massive Sulphides is not so far estimated to have had a significant impact on global resources of metals and the mining of manganese nodules and cobalt rich crusts is not yet technologically feasible. However, the availability of critical metals required to manufacture electrical products is becoming scarce and the alternative sources of these metals, such as seabed mining, pose significant environmental concerns.

There are solutions to this problem, including increased efficiency of use and recycling of the metal resources we already have, supported by better product and manufacturing process design. For example, the increasing volumes of waste electronic and electrical equipment are seen by some as reservoirs of 'urban ore' from which critical materials can be extracted and recycled. In fact, responsible e-waste recycling is best achieved through systems of takeback of end-of-life products by manufacturers, where the component materials can be safely and effectively recovered and reused. Closing the loop on metals use and recycling can be a far more efficient way to source metal than mining virgin ore, while increasing self-reliance on national reserves and reducing both pollution and waste of energy and resources. .

In many parts of the world, legislation now requires that manufacturers of electronic and electrical equipment must not include certain hazardous substances, including some toxic metals, in their products. For example. the EU Restriction of Hazardous

Substances (RoHS) Directive requires that some key hazardous substances in electronics which pose health and environmental problems during the disposal and recycling of e-waste (including lead, cadmium and mercury), be substituted with non-hazardous alternatives (Barba-Gutiérrez *et al.*, 2008).It is imperative that manufacturers globally adhere to such requirements and ensure that recycling of e-waste is done in a responsible and safe way because currently there are major concerns with safety of workers and local communities in countries in which such activities are poorly regluated.

Greenpeace is challenging manufacturers of electronic goods to take responsibility for the entire lifecycle of their products, from production, through manufacture and to the very end of their products' lives. With manufacturer responsibility and appropriate incentives and take back schemes for all products reliant on metals in short or restricted supply, and with safe and non-polluting recycling facilities, closing the loop on metals use and recycling should greatly reduce or even negate altogether the need for any exploitation of seabed mineral resources, thus safeguarding the marine environment from yet another emerging threat.

1. INTRODUCTION

Deep sea mining involves the extraction of minerals such as copper, gold, iron, manganese, lead, zinc and nickel from the seafloor. Interest in deep sea mining began in the 1960’s but the collapse of world metal prices dampened early deep sea mining interests. It is only in the last decade that there has been a significant emergence of commercial interest in deep sea exploration, with a marked increase in the number of applications to the International Seabed Authority (ISA), the autonomous United Nations body responsible for managing the mineral resources of the High Seas. There are currently 17 active exploration licences in the High Seas compared to 8 in 2010. There is also significant exploration activity within national waters, particularly in the Pacific Ocean. Pacific Island Countries (PICs) are dealing directly with other national governments and private companies; deep sea minerals present potential new revenue streams that could support national development goals.

Private companies and governments alike are in the hunt for deep sea minerals in the Atlantic, Indian and Pacific Oceans, driven by the high demand and soaring prices for gold and copper, as well as other metals used in various technologies, such as computers, cars and smartphones. Of particular concern has been the restriction of exported rare earth elements (REEs) by China; China has one-third of the world’s reserves but accounts for 97% of current production, having squeezed out other suppliers with low prices in the 1990s. China is restricting exports to induce foreign technology firms to place operations inside China. During January to June 2011, for example, the quota was cut by 35% (The Economist, 2011).

With recent and ongoing advances in marine technology, deep sea mining is not merely a very real possibility; it is imminent. However, only a limited area of the deep-sea has been scientifically studied (EC, 2007) and there have been no commercial scale mining trials to date. While this inevitably limits the ability to predict the environmental impacts of mining operations and to determine if habitats can recover from this disturbance, given the nature, scale and locations of proposed seabed mining activities serious and, in some cases, widespread negative impacts on habitats and marine life can reasonably be expected.

2. THE DEEP SEA ENVIRONMENT

The deep sea covers about 70% of the Earth and has an average depth of 3,200 metres (Prieur, 1997). About 50% of the deep ocean floor is an abyssal plain comprised mainly of mud flats. Superimposed on the deep sea bed are other deep sea features including submarine canyons, oceanic trenches, hydrothermal vents and underwater mountains called seamounts. This great variety of benthic (sea bottom) habitats support multitudinous life forms. In recent years, scientists have documented hundreds more species living in deep sea habitats; however the vast majority of the deep sea environment remains unexplored.

Deep sea mining has been proposed for different types of seafloor habitats including seamounts, hydrothermal vents, and manganese nodules on the abyssal plain. A brief description of the ecology of these habitats based on current scientific knowledge is described below.

2.1 Seamounts

Seamounts are undersea mountains which are usually formed by volcanic activity and often occur in chains or clusters. Globally, there are estimated to be over 30,000 seamounts rising 1000m or more from the seafloor, and more than 100,000 smaller features. Scientific research to date has been carried out on fewer than 300 seamounts, so the knowledge base on the ecology of seamounts is still very limited.

Some studies have shown that seamount habitats represent a treasure house of biological diversity (McGarvin, 2005).Water currents are enhanced around seamounts, delivering nutrients which promote the growth of animals like corals, anemones, featherstars and sponges (Koslow *et al,.* 2001; Stocks, 2004). These species make seamounts visually striking and consequently seamounts have been likened to underwater gardens due to the branching tree-like and flower-like corals and sponges that cover many of them. Some stands of corals which have been discovered on seamounts are several centuries old. In addition to reef-building organisms such as corals and sponges, other invertebrate species common to seamounts are crustaceans, molluscs, sea urchins, brittle stars and polychaetes (bristle worms) (Stocks, 2004b).

Many species of fish are associated with seamounts (Rogers, 1994) and some are well known for the huge aggregations they form over these features (orange roughy, for example). A study cited by Tracey *et al.* (2004) described 263 species of fish that were found on seamounts in the New Caledonian region. Migratory species such as tuna and marine mammals are also known to congregate over seamounts, which suggests that they are important even for pelagic species (Stocks, 2004b), presumably because of pathways of energy transfer between deep water and surface communities.

Overall, there is evidence that seamounts tend to support a high biomass and abundance of fauna but additional data from a broader range of seamounts is needed to establish whether this is the case in general (Rowden *et al.,* 2010).

It is now common knowledge that the fishing technique of bottom trawling causes extensive damage to seamount habitats. Recent studies of trawled seamounts off Tasmania (Althaus *et al.,* 2009) and New Zealand (Williams *et al.,* 2010) found that there was no clear signal of recovery of the megabenthos where trawling had ceased even after 5-10 years. These studies indicated that a decade may be too short a time to detect any recovery of coral communities. Research suggests that recovery of seamount benthos will take many decades or even greater time periods (Althaus *et al.,* 2009).

Greenpeace is campaigning for the implementation of a global network of Marine Reserves which would protect at least 40% of the world's oceans, including particularly vulnerable areas such as seamounts, from fishing and other threats such as seabed mining (Roberts *et al.* 2006).

2.2 Deep Sea Hydrothermal Vents

A hydrothermal vent is a geyser on the seafloor which gushes hot water into the cold, deep ocean. These hot springs are heated by molten rock below the seabed (Gage and Tyler, 1991). Deep-sea vents have been found in the Pacific, Atlantic, Arctic and Indian Oceans (Little and Vrijenhoek, 2003). They are primarily concentrated along the earth's Mid-Oceanic Ridge system, a continuous underwater mountain chain that bisects the oceans and is a 60,000 kilometre seam of geological activity. It is thought that hundreds, if not thousands, of hydrothermal vent sites may exist along the Mid-Oceanic Ridge but as yet only about 100 sites have been identified because they are very difficult to find (Glowka, 2003).

In 1977, scientists discovered that vents were populated with an extraordinary array of animal life (see text box). These habitats are dominated by large biomass populations of invertebrates (Collins *et al*., 2012), including molluscs, gastropods, tube-dwelling worms, sea anemones and crustaceans (Gage and Tyler, 1991; Little and Vrijenhoek, 2003). Some species of fish have been found to live within vent environments and more live in their vicinity (Biscoito *et al.,* 2002). Many animal species are exclusively native (endemic) to vent sites (Little and Vrijenhoek, 2003; Van Dover 2010). Hydrothermal vent habitats are thus considered to hold intrinsic scientific value (Van Dover *et al*., 2012).

Hydrothermal vent communities were first discovered in 1977 but since then only 10 % of the deep sea has been explored for these unique habitats (Baker and German, 2004). At around 2000 m depth, these vents have high temperatures (up to 400 °C) and are highly acidic (pH 2-3) yet support vast communities of organisms (Ramirez-Llodra *et al*., 2007). Chemosynthetic bacteria, which use hydrogen sulphide as energy, form the basis of the vent food web.

There are six major sea floor regions, each populated by distinct species. For example, in the West Pacific Ocean vents are dominated by barnacles and limpets but in the East Pacific Ocean vents are dominated by 2 m tall tube worms. Over 550 vent species have been discovered so far including crabs, snails, shrimp, octopus and fish (Desbruyères *et al*., 2006). Around 85 % of vent species are considered to be endemic (Ramirez-Llodra *et al*., 2007) with an average of two new vent species described every month in the 25 year period following their discovery (Van Dover *et al*., 2002).

2.3 Manganese Nodules

Manganese nodules take millions of years to form. Organisms can be found on the surfaces of manganese nodules as the provide one of the only hard substrates on the abyssal sea floor. Only a few studies have been conducted on nodule fauna, however, due to their delicate natures and occurrence only at great depths (Viellette *et al.* 2007). Sponges and molluscs can adhere to the outer surfaces, while nematode worms and crustacean larvae have been found within nodule crevices, fauna distinctly different from that in the surrounding sediments and in some cases unique to such structures (Thiel *et al.* 1993). For example, the worm *Acantholaimus maks* has only ever been reported in nodule crevices in the Peru Basin. In addition, up to 20% of outer nodule surfaces can be colonised by microscopic organisms, especially foraminiferans, many of which were new to science when discovered on nodules (Mullineax 1987).

3. COMMERCIAL INTEREST IN DEEP SEA MINING

3.1 *Manganese Nodules (MN)*

Manganese nodules form on the vast deep water abyssal plains and are composed primarily of manganese and iron but with significant amounts of nickel and copper. Cobalt is also present in lower concentrations. In addition, there are traces of other significant elements such as platinum or tellurium that are important in industry for various high-tech products (Hein, 2012; Bollmann *et al*., 2010). Nodules of economic interest have been found in four areas: the Clarion-Clipperton Fracture Zone in north-central Pacific Ocean, the Penrhyn Basin in south-central Pacific Ocean, the Peru Basin in the south-east Pacific, and the centre of the north Indian Ocean. In the Pacific Islands region, the most promising deposit in terms of nodule abundance and metal concentration known to date occurs within the Exclusive Economic Zone (EEZ) of the Cook Islands. Other potential areas are the two eastern island groups of Kiribati (Phoenix and Line) and to a lesser extent the Gilbert Islands (Kiribati) and within the EEZ of Tuvalu and Niue (Secretariat of the Pacific Community, 2011) .

Extraction of manganese nodules from the Clarion Clipperton Zone in the North Pacific Ocean is governed by the International Seabed Authority, as it is in international waters. There are 12 different companies which own pioneering mining contracts in this region (ISA, 2013c), with each contract area totalling 75 000 km^2 (Ramirez Llodra *et al.,* 2011). The nodules occur between 4000 – 5000 m deep and contain high concentrations of copper, nickel and manganese (ISA, 2013a). Mining operations are currently in the feasibility study stage, with no applications for provisional exploitation licenses expected until at least 2016 (ISA, 2013b).

3.2 *Cobalt-rich Crusts (CRC)*

Cobalt-rich crusts, also referred to as ferromanganese crusts, form on seamounts and contain manganese, iron and a wide array of trace metals (cobalt, copper, nickel, and platinum)(Hein, 2012; Bollmann *et al*., 2010). Based on grade, tonnage, and oceanographic conditions, the central equatorial Pacific offers the best potential for crust mining, particularly within the EEZ of Johnston Island (USA), the Marshall Islands, and international waters in the Mid-Pacific Seamounts. The EEZs of French Polynesia, Kiribati and the Federated States of Micronesia are also considered as potential crust locations and minor occurrences of crusts have also been recorded in Tuvalu, Samoa and Niue. Cobalt-rich Crust mining is much more technologically challenging than Manganese Nodule mining as crusts are attached to rock substrates. Cobalt is the most important of the elements in nodules and crusts with respect to the price and as a strategic metal that is indispensable for super-alloys used, for example, in jet aircraft engines (Secretariat of the Pacific Community, 2011) ;Bollmann *et al*., 2010).

3.3 *Seafloor Massive Sulphide (SMS)*

Seafloor Massive Sulphides form at hydrothermal vents (black smokers) along oceanic ridges and contain sulphur-rich ore (Hein, 2012; Bollmann *et a*l., 2010). SMS are rich in copper, gold, zinc, lead, barium and silver (Hein, 2012). More than 200 sites of hydrothermal mineralisation are known to occur on the seafloor and, based on previous exploration and resource assessment, about ten of these deposits may have sufficient size and grade to be considered for future mining.

Potential sites include:

- The Atlantis II Deep in the Red Sea (Saudi Arabia & Sudan);
- Middle Valley (Canada);
- Explorer Ridge (Canada);
- Galapagos Rift (Ecuador);
- The East Pacific Rise 13°N in the Pacific Ocean;
- The TAG hydrothermal field in the Atlantic Ocean;
- The Kermadec Arc (New Zealand);
- The Manus Basin (Papua New Guinea (PNG));
- The Lau Basin (Tonga);
- The Okinawa Trough (Japan);
- The North Fiji Basin (Fiji) (Secretariat of the Pacific Community, 2011) ; Nautilus Minerals Inc., 2012).

All of these sites except two (East Pacific Rise 13°N and TAG hydrothermal field) are located within the EEZs of coastal states. Aside from PNG, Fiji and Tonga, SMS deposits or indications of SMS deposits are also reported to have occurred within the waters of Solomon Islands, Vanuatu and Palau. Ongoing exploration and resource evaluation indicate that polymetallic SMS deposits in the Pacific region have higher copper concentrations with significant enrichment in zinc, gold and silver and are also located in comparatively shallow water (less than 2000 metres) (Secretariat of the Pacific Community, 2011) ; Bollmann *et al*., 2010).

Mining of hydrothermal vents for seafloor massive sulphide deposits is planned in the Bismarck Sea within the EEZ of Papua New Guinea by Nautilus Minerals Inc. (Nautilus). The company will focus on the extraction of high grade copper and gold at depths between 1500 – 2000 m (Nautilis Minerals, 2008). Although there are 12 designated prospecting sites, the first site proposed to be mined is known as Solwara 1 with an area of 0.112 km^2 (Nautilus Minerals, 2013). Environmental and mining licenses were granted by the Papua New Guinea government in August 2012, with commercial production planned by the end of 2013. However, recent disputes between Nautilus and the Papua New Guinea government have halted equipment construction and potential mining operations at the time of publication of this review.

Technologically, the ability and viability to explore and extract various marine mineral deposits is somewhat determined by the depth at which these minerals are found.

3.4 *Iron Sands (Iron ore)*

Iron is extracted from iron ores, which are commonly found in rock. The main objective in extracting iron ore is to make steel. Offshore iron sands (or black sand) are composed of a type of iron oxide called titanomagnetite which can also yield ore. The iron sand also contains the valuable minerals titanium and vanadium, which can be extracted in the steel making process to create extra value. Offshore sands containing iron minerals are common around the world and are found within several exclusive economic zones (OceanflORE, 2011; Trans-Tasman Resources, 2011b; Trans-Tasman Resources, 2011c).

3.5 *Offshore phosphate*

Marine sedimentary phosphorite deposits are naturally occurring compounds containing phosphate in the form of cement binding sediment. Phosphates extracted from phosphorites are composed of calcium phosphate. Offshore phosphates are usually found off the west coast of continents on the continental shelf (in the EEZ) but are also found as seamount and plateau deposits in the High Seas (Hein, 2012; OceanflORE, 2011). Examples of offshore locations where they have been found include: Peru, Chile, Namibia, eastern Australia, Baja California (Mexico), Blake Plateau (United States), Chatham Rise (New Zealand) and the island of Nauru (south western Pacific) (OceanflORE, 2011).

Seamount phosphorite deposits in the Pacific and Atlantic may also potentially provide additional sources of rare earth elements (Hein, 2012).

The mining of phosphate deposits within the Namibian EEZ is a joint venture between Australian mining companies (Union Resources Ltd and Mawarid Mining) and Tungeni Investments cc. (Namibian Marine Phosphates, 2013), and is known as Namphos. This project is called the Sandpiper project and is located 120 km off Walvis Bay, between 180-300 m deep. A 20 year mining license, pending an environmental impact assessment, was issued by the Namibian Government in July 2010 for an area of 2233 km^2. This assessment was submitted in March 2012 but not approved due to 'inadequate consultations with interested and affected parties' (McClune, 2012). Namphos plan to start commercial production by the end of 2013 (Hartman, 2013).

4. <u>MINING TECHNIQUES AND THEIR IMPACTS ON THE SEABED AND BIOTA (LIFEFORMS)</u>

4.1 Mining Techniques

All seabed mining operations follow a similar system using a seabed resource collector, lifting system and support vessels to transport the ore. Most proposed seabed collection systems envisage the use of remotely operated vehicle techniques which extract deposits from the seabed using mechanical or pressurised water drills. Currently diamond mining off the coast of Namibia uses either a hose attached to a ROV to collect shallow diamond bearing gravels or a drill to reach deeper gravel deposits (De Beers, 2011). Another mining technique is dredging. Dredging is proposed for mining phosphates off the coast of Namibia and New Zealand (Chatham Rock Phosphate Ltd, 2012; McClune, 2012).

4.2 Release of Sediment and Wastes from Mining

Dewatering waste, side cast sediment and sediment released during the mining process are thought to be the main wastes associated with the recovery of seabed minerals. Dewatering waste may contain fine sediment and heavy metals which are resuspended when discharged into the water column (Nautilus Minerals, 2008). Aggregations of suspended particulate matter and settlement of sediment could cover a wide area depending on currents and discharge volume, physically changing seabed topography. Sediment plumes would smoother habitats and flora and fauna and, depending on their origins and composition, could result in the exposure of benthic communities to heavy metals and acidic wastes (Van Dover, 2010). Discharges into surface waters from some types of operations could lead to algal blooms, turbidity clouds and impacts on commercial fish species (Namibian Marine Phosphates, 2012). The release height of dewatering discharge may help to mitigate to some degree the impact of sediment plumes in the water column (Agarwal *et al.,* 2012). If released close to the seabed, models suggest that the plumes should be confined to deep water and not move into the upper water column due to differences in water density (Bashir *et al*., 2012). However it is difficult to model this system without extensive plume data, upwelling and current information (Luick, 2012), and even in such situations, some scale of impacts on benthic communities cannot be avoided.

It is likely to be impossible to restrict impacts of sedimentation or the release of metals to a local mining area due to current movements and the unconstrained nature of the oceans. Depending on the scale of mining, impacts could spread between ocean basins, far away from original mine sites and could lead to disputes as impacts spread from territorial to international waters or vice versa (see section 5). For example, tailings disposed of at sea from the Lihir Gold mine in Papua New Guinea are estimated to have spread over an area of 60 km^2 from the point of discharge due to subsurface currents (Shimmield *et al.,* 2010).

Side casting sediment waste on the seafloor minimises the need for transport to the surface or land based storage, but would nonetheless lead to major physical alterations and smothering of the benthic habitat. In relation to its proposed mining of the Solwara 1 Zone in the waters of Papua New Guinea, Nautilus Minerals state that their waste sediment and rock, an estimated 245 000 t (Nautilus Minerals, 2008), will be side cast at the edge of the mining zone.

4.3 Impacts of mining on the Seabed

Remotely operated machines would inevitably cause direct physical impact to the seabed, changing its topography through suction or drilling and removal of the minerals as well as though machinery movements themselves. Removal of benthic substrates and mining vehicle use is expected to alter the seabed, leaving a flatter and more uniform surface in many areas with compressed sediment underneath which could be unsuitable for recolonisation and habitat recovery. In addition, using ROVs has potential to cause pollution via spills of hydraulic fluid, but this has not so far been considered in detail in published literature (Steiner, 2009).

<u>Hydrothermal Vents</u>: Mining will completely remove targeted hydrothermal vent chimneys leaving a flatter topography, waste material and loss of habitat for vent species. Van Dover (2010) does suggest that the mineral component of chimneys could physically reform over time if the vents remain active(Hekinian *et al.* (1983) reported physical chimney growth of 40 cm over 5 days at some locations in the East Pacific Rise). However, it is unknown how long it would take for the recovery of their associated ecosystems, and indeed whether recolonisation would occur at all.

<u>Manganese Nodules</u>: Nodules are known to take millions of years to form due to slow accretion rates of 1 – 2 mm per million years (Ghosh and Mukhopadhyay, 2000). Mining would remove the nodules. Their extraction would remove some of the only hard substrate present on the abyssal sea floor, resulting in habitat loss and possible localised extinction of nodule animals (Glover and Smith, 2003)

Phosphate mining: Proposed mining ventures for phosphates in Namibian waters are expected to involve dredging of an estimated 60 km^2 area of seabed down to a depth of 3 m over a 20 year license period (Midgley, 2012), flattening the seabed and exposing underlying hard substrates. The use of dredging in fisheries removes the top layer of sediment resulting in scouring and resuspension of material, as well as changing the seabed's physical topography. It is almost certain that the use of dredging as a mining technique will cause the same impacts. Such altered conditions could even favour increases in jellyfish populations as large extents of hard substrates provide a suitable environment for polyp development.

Exploratory Investigations: In addition to the impacts of mining operations, exploratory investigations may also have impacts in and of themselves. They are also likely to change the physical structure of the seafloor due to machinery use and removal of substrates, albeit on a smaller scale than those envisaged for commercial seabed mining operations, but this could still have damaging impacts on the deep-sea ecosystem. Godet *et al.* (2011) noted that the impacts from precision exploratory sampling are generally small but there can be indirect effects due to lighting and poor vehicle control.

4.4 Impacts of Mining on Flora and Fauna

The removal of habitat by deep sea mining using ROVs or dredging would remove and kill much of the local flora and fauna. It can be predicted that:

- Sessile (stationary) organisms impacted directly by mining machinery and processes would be killed;
- Motile organisms may migrate away from mining areas due to environmental disturbance, but may not avoid all impacts;
- All types of mining would increase smothering and clogging of filter feeding organisms as a result of exposure to sediment plumes and dewatering waste.
- There is likely to be some direct bathypelagic fish mortality caused by all mining operations, as well as further impacts as a result of a decline in food sources.
- For manganese nodules specifically, it is unlikely that nodule fauna would return to previous levels after mining since nodules take millions of years to form (Glover and Smith 2003).
- For cobalt-rich-crust (CRC) deposits located on seamounts, mining is likely to cause bathypelagic and mesopelagic fish mortality, as well as extensive damage to other species.

High mortality of sediment-dwelling (infaunal and epifaunal) organisms due to direct removal, burying in side-cast sediment or smothering by resettlement of suspended sediment are widely recognised consequences of fishing using sediment dredge techniques. Similar impacts have been reported in experiments on nodule collection and sediment disturbance (e.g. Thiel, 1992; Bluhm, 1994).

Further impacts on flora and fauna from deep sea mining operations are likely to occur due to increases in underwater noise, use of underwater lights and/or induced changes in temperature (see below).

4.4.1 *Noise*

Remotely operated vehicles will increase underwater ambient noise, as will support vessels situated at the sea's surface. Most deep-sea species experience relative silence in the environments they inhabit so any introduced noise will likely represent a substantial increase on ambient sound levels (Bashir *et al*., 2012). Studies on deep sea fish reveal that some species appear to communicate using low sound frequencies (<1.2 kHz)(Rountree *et al*., 2011) and it is thought that other benthic species may use sensitive acoustic systems to detect food falls of up to 100 m away (Stocker, 2002). Marine mammals such as whales are, of course, also known to use sound for communication and navigation, systems that might also be impacted by introduced noise of vessels and sub-sea machinery.

Despite legitimate concerns, this remains an understudied stress on deep-sea organisms. To date, it appears that no thorough investigations of ambient noise or sound attenuation have been undertaken by the mining company Nautilus Minerals in relation to its proposed operations, for example, though the company states that it expects seabed noise to be attenuated within 2 km of the mining sites. Steiner (2009) disagrees, stating that noise from the operations could even be detectable up to 600 km from the site, potentially resulting in far field impacts. Nautilus Minerals do acknowledge that mining noise may impact deep diving whales (Nautilus Minerals, 2008).

4.4.2 *Underwater Light*

Mining activity operating 24 hours a day, 365 days a year, such as is proposed by Nautilus Minerals (2008) in PNG, would increase light levels in the deep-sea as a result of operating machinery. The benthic environment is dark and organisms are adapted to these low light conditions (Bashir *et a*l., 2012). For example, Herring *et al.* (1998) reported that deep sea shrimp species have been blinded by lighting on scientific research equipment which visited the area for only a few hours. If increased light levels persisted for some time, this could damage organisms and result in migration away from the mined site. To date, there is no evidence that Nautilus Minerals have investigated ambient light levels at the Solwara 1 site or considered the likely significance of these impacts in any detail (Nautilus Minerals, 2008).

4.4.3 *Increased Temperature*

Drilling and vehicle operation would release heat, possibly leading to local increases in water temperature (Nautilus Minerals, 2008). Dewatering waste returned to the deep-sea may be warmer than ambient water temperatures, with Steiner (2009) suggesting an increase of as much as11°C in some instances. Deep-sea organisms exist in a stable temperature environment, so increases in ambient temperature could cause negative impacts; in practice, however, very little is known about the potential impacts of excess heat on the growth, metabolism, reproductive success and survival of deep-sea species (Bashir *et al.,* 2012).

4.4.4 *Far Field Impacts*

Far field impacts are classified in this report as those which may be expected to be detectable over 10 km away from the mining site and could include impacts of drifting sediment plumes and noise pollution. For example, for the Solwara 1 project, there are concerns that sediment plumes from mining operations could drift from territorial into international waters (Halfar and Fujita, 2002).

4.5 Potential Recovery of Benthic Communities from Mining Operations

4.5.1 *Potential and Likelihood of Community Recovery*

The potential for benthic community recovery is likely to vary substantially from location to location, depending on habitat and on the type of mineral mined, the technique used and the length of the operation (Van Dover, 2011). Due to the lack of commercial operations so far, the potential for recovery is often determined using natural extinction events such as volcanic eruptions or disturbance experiments with follow up monitoring. For obvious reasons, recovery studies have not been conducted on a spatial or temporal scale similar to those planned for commercial seabed mining, following which the potential for colonisation from adjacent areas may be considerably reduced.

Deep-sea organisms commonly have slow growth rates, partly due to low water temperatures and limited food resources, and are therefore thought to have low resilience to changes in the benthic environment (Rodrigues *et al*., 2001; Rosenbaum, 2011). Due to this, recovery may be slower than anticipated and additionally affected by further mining operations. In the case of massive sulphide deposits, it is thought that there would be some level of post-mining recovery of the physical structure of the seabed (Nautilus Minerals, 2008) but recovery to baseline conditions is unlikely other than over extremely long time-scales. Community composition changes may occur due to recolonisation of substrates by opportunist species (Bashir *et al*., 2012) and the loss of species sensitive to change.

Hydrothermal vent community recovery is reliant on the continuation of the hydrothermal energy source and species to repopulate (Rosenbaum, 2011). Observations by Mullineaux *et al.* (2010) indicated recolonisation of a vent following a natural volcanic eruption, but with a change in species composition and the presence of immigrant species from distant vent sites, possibly up to 300 km away. Shank *et al.* (1998) monitored a hydrothermal vent eruption and its recovery. It took between three to five years post-eruption before there were large increases in faunal assemblages and the authors predicted it would take up to 10 years before the dominant megafauna returned. However, it is important to note that sustained mining operations may have very different impacts to those of single natural events (Van Dover, 2011), and the likelihood and extent of recovery of mined vent sites must be considered highly uncertain at best.

The extraction of manganese nodules removes the habitat for nodule dwelling organisms, making recovery for these communities almost impossible given the long time periods required for nodule formation. In the case of impacted stands of corals and/or sponges associated with mining operations on or around seamounts, recovery of these slow growing species and their associated species assemblages is likely to take decades or even centuries.

4.5.2 *Proposed Mitigation Techniques*

In order to protect biodiversity and aid recovery of mined areas, a series of mitigation techniques have been suggested, although all are untested so far and their success unknown (Rosenbaum, 2011). Van Dover (2011) stressed that we simply do not know how to mitigate impacts or restore deep-sea habitats successfully. Given the nature of proposed techniques, mitigation of some impacts may simply be impossible if exploration and exploitation are allowed to proceed.

Establishing refuge areas have been suggested as a possible mitigation method. However, the ISA's International Mining Code has no criteria for establishing Preservation Restoration Zones (refuge areas) so it is currently up to mining companies to decide the locations and sizes of such areas (ISA, 2010).The Nautilis Solwara 1 project proposes the use of a refuge site (see section 6.1) although it is uncertain whether this would be successful as their strategy is, inevitably, untested. Proposals for phosphate mining in Namibia advocate the use of conservation corridors to provide refuge areas for species displaced due to mining and, in theory, to allow recolonisation once mining practices have finished (Rogers and Li, 2002) (seesection 6.1).

4.5.3 *Mining of Extinct Vents*

Mining of extinct vents only is anticipated to minimise impacts to vent species, as extinct sites are considered to have fewer species. Extinct vents are largely unstudied due to the difficulty in locating them without a hydrothermal plume; this makes them even less understood than active systems (Van Dover, 2010). Moreover, it is hard to determine if a vent is extinct or just temporally inactive, with reports of some vent systems being inactive for several years and then becoming active again (Birney *et al*., 2006). For example, vent activity was highly variable over a three year period of investigation at Solwara 1 (Nautilus Minerals, 2008). Suzuki *et al.* (2004) reported that inactive vents still supported the growth of chemolithotrophic microorganisms as there was sufficient hydrothermal energy. Van Dover (2010) noted that extinct vents with no detectable emissions nevertheless still hosted suspension feeding and grazing invertebrates. Such ‘extinct’ or inactive vent systems may therefore prove to be far from extinct in relation to marine life.

5. POSSIBLE CONFLICTS OF MINING WITH OTHER HUMAN ACTIVITIES

Possible conflicts of interest relating to mining claims include commercial and subsistence fishing, oil and gas exploration and shipping. Bioprospecting for new medicines and other useful substances from deep sea flora and fauna is also an area of growing interest and one with which mining activities may conflict. A UNEP (2012) report noted that the destruction of deep-sea ecosystems due to mining may result in the loss of future resources of which humans are currently unaware.

5.1 Fisheries

Surface exclusion zones are proposed around seabed mining operations, and these may significantly reduce access to fishing areas and/or change shipping or navigational routes in some instances. In the case of Namibia, an exclusion zone of 23 x 9 km has been proposed, which would impact on key commercial fishing grounds for hake, horse mackerel and monkfish (Namibian Marine Phosphates, 2012). It is reported that fishing activities will stop in the immediate mining area and the exclusion zone due to habitat removal and increased levels of maritime traffic noting that “there are no realistic options” in their view to mitigate the loss of fishing grounds (Namibian Marine Phosphates, 2012).

5.2 Oil and Gas

As exploration for hydrocarbon reserves moves into deeper water, it could come into conflict with regions of either proposed or active seabed mining. Currently, the Namibian EEZ has growing amounts of oil and gas exploration and oil tankers travel through its waters from Angola to China (Midgley, 2012). The PNG government has recently decided to focus more attention on producing liquefied natural gas with ExxonMobil, diverting some funds previously allocated to SMS mining projects (McCalister, 2013).

5.3 Marine Genetic Resources, Pharmaceuticals and Other Useful Substances

Armstrong *et al.* (2012) reported that the deep-sea is the largest reservoir of genetic resources and many companies already hold patents for pharmaceuticals discovered there. For example, enzymes in deep-sea bacteria have been used to develop commercial skin protection products by the French company Sederma (Arico and Salpin, 2005). Hydrothermal vent species are of particular interest as they have unusual symbiotic relationships, are resistant to heavy metals and can live at high temperatures and pressures (Ruth, 2006). Enzymes from hydrothermal vent species are estimated to have an annual commercial value of $150 million, with the enzyme market as a whole valued at a minimum of $50 billion per year (United Nations

University, 2007). Despite the high commercial value of these deep-sea discoveries, there are concerns that mining could destroy genetic resources before they are fully understood or even discovered. There are also uncertainties surrounding intellectual property rights associated with discoveries made whilst mining (Ruth, 2006; Sarmiento, 2013).

6. CASE STUDIES OF 3 PROPOSED MINING SITES AND THEIR PREDICTED IMPACTS ON THE DEEP SEA ENVIRONMENT AND ON FISHERIES

This section describes 3 case studies for the mining of seafloor massive sulphides (SMS), manganese nodules (MN) and phosphates in the marine environment.

6.1 Seafloor Massive Sulphides in Papua New Guinea

Nautilus Minerals Inc. (Nautilus) plan to mine hydrothermal vents for SMS deposits in the Bismarck Sea, within the Exclusive Economic Zone (EEZ) of Papua New Guinea (Nautilus Minerals, 2008) . There are 12 designated prospecting sites owned by Nautilus, although initially only one site with an area of 0.112 km^2 called Solwara 1 would be mined. An estimated 1.3 million tonnes of material a year would be extracted from this site (Nautilus Minerals, 2012). The project is projected to have a lifespan of 2.5 years and will focus on the extraction of high grade copper and gold at depths around 1500 – 2000 m (Nautilus Minerals, 2008). In April 2012, Nautilus signed its first customer, Tongling Nonferrous Metals Group Co. Ltd based in China, for its mined product (Nautilus Minerals, 2012).

Environmental and mining licenses have been granted by the PNG government (Nautilus Minerals, 2012), despite environmental concerns. Luick (2012) argues that the 'EIS fails to provide the basic information needed to assess the risk of pollution of the environment or the risk to the local communities'. It is reported that the PNG government does not have appropriate deep sea mining policies in place and its maritime boundaries have not been fully established (Wilson, 2012).

Nautilus Minerals state that 'the extent of the impacts to vents and other seafloor habitats directly mined will inevitably be severe at the site scale' but argue that mitigation measures would ensure that the overall ecological impact would be 'moderate' (Nautilus Minerals, 2008). Rosenbaum (2011) argues that as these mitigation measures have not been tested, they are unlikely to be completely successful and so the overall ecological impact would be higher. Nautilus propose to remove large organisms and clumps of substrate before mining, move them to a refuge area and transplant them back to their original region once mining has finished (Nautilus Minerals, 2008). Species which are known to be slow growing such as Bamboo Coral (*Keratoisis* sp.) could also be transplanted onto artificial substrates to enhance their growth, allow repositioning and aid recolonisation post-mining (Nautilus Minerals, 2008). However, Nautilus have not tested their proposals and it is unlikely that a whole ecosystem could be successfully transferred to a refuge site and then transplanted again back to the original site after mining. Nautilus propose to use a refuge site (South Su) 2 km away from the Solwara 1 mine site within the same hydrothermal system. Both sites share the same dominant assemblages (Collins *et al*., 2012). If the hydrothermal system was damaged during mining or became inactive, recolonisation from South Su to Solwara 1 may be limited. There is also concern that sediment plumes could be transported to South Su, again impacting its ability to maintain species for recolonisation.

PNG commercial fisheries are located predominantly on the southern coast of the island (the Solwara 1 mining operation is off the north coast) and are dominated by longline and purse seine tuna (skipjack and yellowfin) fisheries, although high catches of reef associated fish are also recorded (FAO, 2010). The PNG National Fisheries Authority (NFA) has raised concerns over mining impacts on tuna fisheries and the lack of marine regulatory policy in PNG. The NFA managing director Mr Pokajam was quoted as suggesting that ‘PNG should ban sea bed mining in its territorial and archipelagic waters’ (Wrakuale, 2012). No further published information or scientific studies on fisheries around the Solwara 1 mine site have been located.

6.2 Manganese Nodules in the Clarion Clipperton Zone

Twelve different companies own pioneering mining contracts issued by the International Seabed Authority for MN extraction in the Clarion Clipperton Zone (CCZ) in the North Pacific Ocean (ISA, 2013c). The CCZ holds an estimated 34 billion tons of manganese nodules (Morgan, 2000) and each contract is issued for an area of 75 000 km^2 (Ramirez Llodra *et al.,* 2011). These nodules are up to 10 cm in diameter, occur at depths around 4000 – 5000 m and contain elevated concentrations of metals such as copper, and nickel, as well as manganese (ISA, 2013). Extensive nodule prospecting began in the 1970s but has since declined due to the decrease in metal prices and economic feasibility of mining at such depths. Within the CCZ, nine regions were designated as Areas of Particular Environmental Interest as part of an environmental management plan administered by the International Seabed Authority, which prohibits mining for nodules in these regions. These areas are designed to protect biodiversity in the CCZ in view of anticipated mining (ISA, 2013b).

As previously discussed, after complete removal of nodules, their recovery is unlikely given they take millions of years to form. There have been a number of experiments investigating the impact of nodule removal on the benthic environment conducted in the CCZ. Results are highly variable. For example, an experimental extraction of nodules from the CCZ was conducted as long ago as 1978 (the so-called OMCO experiment), and the area revisited in 2004 to assess the recovery of the benthic habitat. Despite the ensuing 26 years, tracks were still clearly visible due to the mining vehicles and a reduced diversity and biomass of nematode worms was detectable (Miljutin *et al.,* 2011). In another experiment, however, increases in overall meiobenthic fauna abundance were found in areas which had received sediment deposition, while vehicle tracks were eroded and not clearly visible, two years after the initial experiment (Radziejewska, 2002). These differences in nature and persistence of impacts likely relate in part to differences in natural sediment composition and deposition rates between these two areas (Ingole *et al.,* 2001), as well as to differences in the types of disturbance created in the experiments.

It is also important to note that the experiments carried out to date were conducted on much smaller scales than suggested commercial operations; some did not involve recovery of nodules and, to date, no studies have assessed impacts on fauna dwelling on the nodules themselves.

6.3 Phosphates off the coast of Namibia

Namphos is a joint venture between Australian mining companies (Union Resources Ltd and Mawarid Mining) and Tungeni Investments cc (Namibian Marine Phosphates, 2013). They plan to develop the mining of phosphate deposits, known as the Sandpiper Project, 120 km off the coast of Walvis Bay in water depths of 180 – 300 m and costing around $350 million (). Estimated reserves of 1951 Mt of unconsolidated phosphate, with a concentration of 20 %, were discovered in 1970s but it has since been uneconomical to extract them. With increasing demand and declining terrestrial reserves, a 20 year mining license for an area of 2233 km^2 was granted by the Namibian Government in July 2010, pending an environmental report (Namibian Marine Phosphates, 2013). The Environmental Impact Assessment was submitted to the government in March 2012 but is yet to be approved due to 'inadequate consultations with interested and affected parties' (McClune, 2012). It is hoped by the mining companies that production would begin by the end of 2013 and that the recent new partner, Mawarid Mining, would 'significantly fast-track the development of the Sandpiper project' (Hartman, 2013).

The Namphos mining area is within the Benguela Current, a known area of high primary productivity and abundance of fish (Midgley, 2012). Phosphate extraction is expected to reduce food sources and impact benthic habitats, negatively impacting local fish populations. Namphos note that the biodiversity impacts will be severe in the immediate mining area (Namibian Marine Phosphates, 2012). Removal of phosphate gravels down to 3 m would expose the underlying hard substrate and could encourage a shift to an increasingly jellyfish- dominated rather than fish dominated ecosystem. There is some evidence that jellyfish populations can benefit from an increase in the availability of hard substrates (Duarte *et al*., 2012), leading in turn to competition with fish for food and increased predation on fish eggs and larvae (Lynam *et al.,* 2006; Richardson *et al*., 2009).

There are additional concerns that sediment extraction could release trapped hydrogen sulphide due to changes in pressure, causing release into the water column and impacts on commercial fisheries and other marine organisms (Weeks *et al.,* 2004). It has also been hypothesised that exposure and resuspension of anoxic sediment due to dredging could lead to an increase in *Clostridium botulinum* type E in the water column, posing a health risk if it enters into the food chain (Midgley, 2012). Phosphates are known to contain naturally occurring radioactive material such as uranium and thorium, along with their decay products. As is the case for land-based deposits in other parts of the world, subsequent processing and waste containment in tailings ponds would concentrate these radioactive materials into waste products which in turn may impact the environment (Namibian Marine Phosphates, 2012).

There are some suggested mitigation strategies relating to this project, the main being the establishment of conservation corridors to provide refuge areas for marine species (Rogers and Li, 2002).To date, however, little information has been provided on their proposed location or size. Swakopmund Matters, a Nambian environmental group, campaign against the proposed mining plans arguing that mining should not occur due to its impact on local fishing industries and suggesting instead that the area be declared as a marine reserve (Subsea World News, 2012). As there is limited published environmental information and few scientific studies relating to the area, it is difficult to assess the likely impact of phosphate mining on the Namibian marine environment. However, due to its location within the Benguela Current and proposed mining method, it is probable that the operation could have significant negative impacts on the marine ecosystem, even beyond the immediate mining area.

7. <u>COMMERCIAL INTERESTS IN SEABED MINING</u>

7.1 Types of Resource

Commercial interest in seabed mining stems largely from the potential yield of a wide range of metal deposits, as well as interest in phosphates in some areas. Table 2 summarizes all contracts that have been granted to explore marine deposits on the high seas that have been approved to date. Table 3 summarizes all current mining projects and exploration contracts currently in place within EEZs.

Most licenses granted for exploration of the high seas are for investigation of manganese nodules. At present, however, the commercial mining of both nodules and cobalt-rich crusts is not technologically feasible. Most current commercial interest is therefore currently focused on seafloor massive sulphides, especially in back-arc basins within 200 miles of the coastline (and therefore inside national EEZs), and in shallower water depths of less than 2km (Bertram *et al.*, 2011; Hoagland *et al.*, 2010).

7.1.1 *Seafloor Massive Sulphides*

Despite its relevance in relation to current commercial interest, in contrast to metal resources on land, marine mining of massive sulphides is not presently expected to have a significant impact on global resource supply (Bollman *et al.*, 2010; International Seabed Authority, 2008b). Estimates of land-based resources of such deposits typically fall within the range of 50-60 Mt (million tonnes). Most marine deposits are small: between 1 and 5 Mt (Hoagland *et al.*, 2010). Nautilus's Solwara 1 mine in the Bismarck sea, for example, has an indicated resource of 0.87 Mt, with 1.3 Mt of inferred resource (Hoagland *et al.*, 2010; Lipton, 2012). The one notable exception is Atlantis II Deep (A2D) in the central Red Sea, the world's largest known marine sulphide occurrence (Bertram *et al.,* 2011; International Seabed Authority, 2008b). At 90 Mt, the metalliferous muds of A2D may form the only SMS deposit similar in scale to terrestrial sources (Hoagland *et al.*, 2010).

Seafloor massive sulphides are most likely to yield copper and zinc, though some also contain commercially significant grades of gold (0–20ppm) and silver (0–1200ppm) (Hoagland *et al.,* 2010). Sampling data, to date somewhat restricted and unsystematic, suggest that the metal contents (grades) of some marine sulphide deposits, especially copper, are higher than their terrestrial counterparts .Recent research additionally suggests that seafloor sediment may also be a valuable source of rare earth elements (the lanthanides, plus scandium and yttrium), with estimated reserves of more than 100 million metric tonnes (Kato *et al.*, 2011). That study has, nevertheless, attracted significant criticism, as economic and technological constraints mean that exploiting the resource is unlikely to be feasible, even over the longer-term (Matson, 2011; Hein, 2012).

7.1.2 *Manganese Nodules and Cobalt Rich Crusts*

Should metal prices continue to rise over the longer term, and should technological advances continue to reduce the challenges and capital intensity of sea floor operations, commercial mining of manganese nodules and cobalt-rich crusts – which present altogether different prospects –may be realised in the foreseeable future (Bollman *et al*., 2010; Secretariat of the Pacific Community, 2011; Giurco and Cooper, 2012). In contrast to sulphides, the amounts of several metals, including nickel, cobalt, manganese and the rare earths extracted from these deposits could rival and even surpass onshore resources(Bollman *et al*., 2010; Hein, 2012).

For example, global terrestrial cobalt reserves are estimated at 15 million tonnes, of which about 70,000 tonnes are mined each year (Bollman *et al*., 2010). Crusts and nodules, by comparison, are estimated to contain between 1000 million and a billion tonnes of cobalt (Bollman *et al*., 2010; International Seabed Authority, 2003a). So great is the potential resource that it has been estimated that one seabed mine alone could meet up to a quarter of the annual global demand(International Seabed Authority, 2008a). However, despite technological progress, major stumbling blocks include how to separate crust from substrate (for CRCs) and how to mine an uneven sea floor surface (for MNs); such questions mean that these resources are likely have economic potential only in the longer term (Bollman *et al.,* 2010; Hein, 2012).

Table 2: A summary of mineral exploration contracts on the High Seas approved by the ISA as of April 2013(sources: ISA, 2013c)).

Exploration licence holder(s)	Description of licence holder	Location of licence(s)	Type of mineral exploration	Year contract awarded
China Ocean Mineral Resources Research and Development Association (COMRA) of the People's Republic of China	**Government Research Institute**	**Pacific Ocean (Clarion-Clipperton Zone)** **South-west Indian Ocean Ridge**	**Polymetallic nodules** **Polymetallic sulphides**	**2001** **2011**
Institut français de recherché pour l'exploitation de la mer / Association française pour l'étude et la recherche des nodules (IFREMER/AFERNOD)	**Government Research Institute**	**Pacific Ocean (Clarion-ClippertonZone)** **Atlantic Ocean (Mid-Atlantic Ridge)**	**Polymetallic nodules** **Polymetallic sulphides**	**2001** To be signed
Deep Ocean Resources Development Company Ltd (DORD) of Japan	**Company**	**Pacific Ocean (Clarion-Clipperton Zone)**	**Polymetallic nodules**	**2001**
State Enterprise Yuzmorgeologiya of the Russian Federation	**Government Research Institute**	**Pacific Ocean (Clarion-Clipperton Zone)**	**Polymetallic nodules**	**2001**
Interoceanmetal Joint Organization (IOM) (Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia)	**Consortium of organisations**	**Pacific Ocean (Clarion-Clipperton Zone)**	**Polymetallic nodules**	**2001**
The Government of the Republic of Korea	**Government**	**Pacific Ocean (Clarion-Clipperton Zone)** **Central Indian Ocean**	**Polymetallic nodules** **Polymetallic sulphides**	**2001** **To be signed**
The Government of India	**Government**	**Central Indian Ocean**	**Polymetallic nodules**	**2002**
The Federal Institute for Geosciences and Natural Resources of the Federal Republic of Germany (BGR)	**Government Research Institute**	**Pacific Ocean (Clarion-Clipperton Zone)**	**Polymetallic nodules**	**2006**
Nauru Ocean Resources Inc	**Company**	**Pacific Ocean (Clarion-Clipperton Zone)**	**Polymetallic nodules**	**2011**
Tonga Offshore Mining Ltd, a subsidiary of Nautilus Minerals Inc	**Company**	**Pacific Ocean (Clarion-Clipperton Zone)**	**Polymetallic nodules**	**2012**

UK Seabed Resources Ltd., a wholly owned subsidiary of Lockheed Martin UK Holdings Ltd (LMUK) sponsored by the Government of the United Kingdom	**Government sponsored company**	**Pacific Ocean (Clarion-Clipperton Zone)**	**Polymetallic nodules**	**2013**
Marawa Research and Exploration Ltd., a state enterprise of the Republic of Kiribati	**Government Research Institute**	**Pacific Ocean (Clarion-Clipperton Zone)**	**Polymetallic nodules**	**To be signed**
G-Tec Sea Minerals Resources NV, sponsored by the Government of Belgium	**Government sponsored company**	**Pacific Ocean (Clarion-Clipperton Zone)**	**Polymetallic nodules**	**2013**
Ministry of Natural Resources and the Environment of the Government of the Russian Federation	**Government**	**Mid-Atlantic Ridge**	**Polymetallicss ulphides**	**2012**

Table 3: A summary of Seabed Mining Operations within Exclusive Economic Zones. Text in *italics* indicates mining licences, all other licences refer to exploration.

Licence holder *Country of registration*	Description of licence holder	Location of licence	Type of mineral	Project Status (year awarded if known)
Nautilus Minerals Inc *Canada*	**Publically-listed company**	***Bismarck Sea, PNG(Solwara 1 Project)***	***SMS***	***Active (2011)***
		Solomon Sea & New Ireland Arc, PNG	**SMS**	**Active**
		Kingdom of Tonga	**SMS**	**Active**
		Fiji	**SMS**	**Active**
		Solomon Islands	**SMS**	**Active**
		Vanuatu	**SMS**	**Active**
Diamond Fields International *Canada*	**Ltd company**	***Atlantis II Basin, Red Sea***	***SMS***	***Active (2010)***
Neptune Minerals *USA*	**Publically-listed company**	**Okinawa Trough, Japan**	**SMS**	**Applications lodged**
		Izu-Bonin Arc, Japan	**SMS**	**2007-2008**
		Papua New Guinea	**SMS**	**Expired**
		Kermadec, New Zealand	**SMS**	**Expired**
		Monowai, New Zealand	**SMS**	**Expired**
		Colville, New Zealand	**SMS**	**Expired**
Trans-Tasman Resources *New Zealand*	**Ltd company**	**North Island, New Zealand**	**Iron ore sands**	**Expired 2012**
		North Island, New Zealand	**Iron ore sands**	**Application lodged**
		Continental Shelf, New Zealand	**Iron ore sands**	**Active**
Japan Oil, Gas & Metals National Corp (JOGMEC) *Japan*	**State-funded company**	**Izu & Ogasawara Island Chain & SW Okinawa Islands, Japan**	**SMS & CRCs**	**Active**
Chatham Rock Phosphate *New Zealand*	**Ltd company**	**Chatham Rise, New Zealand**	**Rock Phosphate**	**Active (2010)**
Bluewater Metals Pty Ltd *Solomon Islands*	**Ltd company**	**Solomon Islands**	**SMS**	**Active (2007)**
Green Flash Trading *South Africa*	**Ltd company**	**Western Cape, South Africa**	**Rock Phosphate**	**Application lodged 2012**
Namibian	**Ltd**	***Sandpiper Marine***	***Rock***	***Active (2011)***

Marine Phosphate (Pty) Ltd *Namibia*	**company**	***Phosphate Project, Namibia***	***Phosphate***	
Northern Manganese Ltd *Australia*	**Ltd company**	**Blue Mud Bay Project, Australia** **Groote Eylandt Project, Australia**	**Manganese ore** **Manganese ore**	**Moratorium 2012-2015** **Moratorium 2012-2015**
Fortescue Metals Group *Australia*	**Ltd company**	**West Australia**	**Iron ore sands**	**Active**

7.2 Identification of all existing and proposed seabed mining operations on both the high seas and in national waters (EEZs)

As of January 2013, licences for marine mineral exploration in the High Seas and within Exclusive Economic Zones (EEZs) covered a collective area totalling 1 843 350 km^2 (Hein *et al*., 2013)

7.2.1 *Existing and Proposed Seabed Mining Operations on the High Seas*

The International Seabed Authority (ISA) is an autonomous intergovernmental body established under the 1982 United Nations Convention on the Law of the Sea to organise, control and administer mineral resources beyond the limits of national jurisdiction (ISA, 2013a). To date, the ISA has approved 17 exploration contracts (13 for polymetallic nodules, 4 for polymetallic sulphides), each valid for 15 years, and with each contractor having the exclusive right to explore an initial area of up to 150,000km^2. All licenses are currently active (see Table 2). Twelve of the exploration licences are in the Clarion-Clipperton Zone in the Pacific Ocean, three are in the Central Indian Ocean andtwo are in the Atlantic Ocean (as of April 2013) (ISA, 2013c).

7.2.2 *Existing and Proposed Seabed Mining Operations within Exclusive Economic Zones*

Table 3 is a summary of licenses granted for exploration of resources within EEZ. Note that some of the licenses were granted many years ago and have either expired or no exploration is taking place. The companies involved retain these licenses nonetheless in order to stake their claim for potential future work.

The most advanced of all seabed mining operations is Nautilus Minerals' Solwara 1 Project in the Bismarck Sea, Papua New Guinea (PNG), which was granted a mining licence for SMS deposits in 2011. Diamond Fields International has also acquired a deep sea metal mining license for activities within the Atlantis II basin in the Red Sea, also for SMS deposits, approximately 115 km west of Jeddah. Namibian Marine

Phosphate (Pty) Ltd was granted a 20 year mining licence in 2011 for rock phosphate to be mined offshore from Walvis Bay, Namibia.

7.2.2.1 Nautilus Minerals

The main operational focus of Nautilus Minerals currently is the Solwara 1 Project (high grade copper and gold at SMS deposits) which is located at 1600 metres water depth in the Bismarck Sea, Papua New Guinea (PNG). The Mining Lease was granted in 2011 and covers an area of approximately 59km^2. The Environmental Permit for the development of the Solwara 1 Project was granted in December 2009 by the Department of Environment and Conservation of Papua New Guinea, for a term of 25 years, expiring in 2035 (Nautilus Minerals , 2012).

Nautilus had expected to begin extracting mineralised material from the Solwara 1 deposit in 2013 (first production by the end of 2013), but announced in June 2012 that it was "in dispute" with Papua New Guinea over funding, warning of possible delays in obtaining funds for the project's main vessel from the company's German partner, Harren & Partner (Nautilus Minerals, 2012).

Nautilus Minerals currently has 13 granted Exploration Licences and nine Exploration Licence applications in the Solomon Sea and New Ireland Arc areas of Papua New Guinea. In addition, Nautilus Minerals has tenements in other SW Pacific countries, including:

- 16 granted Prospecting Licenses and a further 30 Prospecting License applications in the Kingdom of Tonga;
- 3 Special Prospecting Licence applications,14 granted Special Prospecting Licences and 3 Special Prospecting Licence applications in Fiji;
- 92 granted Prospecting Licences in the Solomon Islands;
- 41 granted Prospecting Licences and a further 14 Prospecting Licence applications in Vanuatu; and
- 2 Prospecting Permit applications in New Zealand (Nautilus Minerals , 2012).

On 11 January 2012, the International Seabed Authority (ISA) approved an application lodged by Tonga Offshore Mining Limited (TOML), a subsidiary of Nautilus Minerals, in the Clarion-Clipperton Zone. A formal Contract of Work was entered into by both parties on the 11 January 2012. TOML’s application to explore in the Clarion-Clipperton Zone has been formally sponsored by the Kingdom of Tonga (Nautilus Minerals, 2012).

7.2.2.2 Diamond Fields International

Diamond Fields International (DFI), together with its joint venture partner Manafa, acquired a 30-year exclusive deep sea metal mining license in June 2010 for activities within the Atlantis II basin in the Red Sea, approximately 115 km west of Jeddah . The Atlantis basin is comprised of four interlinked sub-basins lying approximately 2,000 meters below sea level and is widely acknowledged as the largest known polymetallic marine ‘sedex’ (sedimentary exhalative) deposit in the world. There is evidence of extensive and continuous mineralization of zinc, copper, silver, gold, lead, and other metals (Diamond Fields International, 2012; Ransome, 2010).

7.2.2.3 Neptune Minerals

In May 2011, Neptune Minerals, Inc. acquired control of Neptune Minerals plc., a UK domiciled company with 3,447 km² of licensed tenements in New Zealand and Japan, and with an additional 84,000 km² of licence applications in process. It has also acquired control of Dorado Ocean Resource Limited, a Hong Kong company which already controlled 80,494 km² of licensed tenements, with applications for an additional 83,484 km² in process and which had been pursuing exploration programs to identify high-grade polymetallic SMS deposits (Neptune Minerals Inc., 2012).

7.2.2.3.1 Neptune Minerals in Japan

By February 2007, Neptune Minerals plc had lodged 133 Prospecting Licence Applications, covering 9 areas highly prospective for SMS, all within the territorial waters of Japan. In 2008, it announced it had lodged an additional 405 Prospecting Licence Applications within the territorial waters of Japan, approximately 500km south of Tokyo and adjacent to three areas covered by Neptune's existing Prospecting Licence Applications (Financial Express, 2008). Research has outlined numerous SMS deposits.

Okinawa Trough

32 applications totalling 110 km^2 were lodged in the Okinawa Trough, a back-arc basin stretching from Kyushu SW towards Taiwan, covering 3 highly prospective areas between 150-200 km north and northwest of the island of Okinawa. Included in Neptune's application areas is the JADE hydrothermal field, where continuing research since its discovery in 1988 has highlighted extensive occurrences of SMS mineralisation over an area of 1800m x 600m. Neptune's applications also cover the Minami-Ensei Knoll and Iheya North areas, both of which contain known SMS mineralisation (Financial Express, 2007).

Izu-Bonin Arc

101 applications totalling 348 km^2 were lodged in the Izu-Bonin Arc in 2007, and a further 405 applications with a total area of 1,400 km^2 were lodged in 2008. Neptune's applications cover 6 highly prospective areas, including the Hakurei hydrothermal field, discovered by Japanese researchers in 2003 approximately 500km south-southeast of Tokyo. Subsequent research has delineated a complex of sulphide mounds and chimneys covering an area of 700m x 500m, at a water depth of around 900m. Neptune's applications also cover the Bayonnaise, Myojin and

Myojinsho Knolls, and the Suiyo and Kaikata Seamounts, all of which contain known SMS mineralisation (Financial Express, 2007; Financial Express, 2008).

7.2.2.3.2 Neptune Minerals in Papua New Guinea

Neptune has lodged five Exploration Licence Applications (ELAs) within the territorial waters of Papua New Guinea (PNG). The applications cover prospective seamounts and other structural features that surround - and are submerged parts of - the island groups comprising the Tabar-Feni Arc. Numerous epithermal gold occurrences are known on these islands, including the Ladolam Deposit on Lihir Island and the Simberi gold deposit in the Tabar Island Group.

7.2.2.3.3 Neptune Minerals in New Zealand

All exploration permits held by Neptune within the New Zealand EEZ have now expired (New Zealand Ministry of Economic Development, 2012), but included:

- Kermadec, one of the company's key seafloor massive sulphide (SMS) projects based in the New Zealand's northern waters. The first commercial exploration drilling programme for SMS took place in 2005 and gold, silver, copper, zinc and lead were discovered from drilling samples of SMS chimneys submitted for metallurgical properties (Odyssey Marine Exploration, 2012). In 2006, licenses were extended to include 12 main seamounts and seamount complexes in the southern third of the Kermadec Volcanic Arc.

- The northern two thirds of the Kermadec Arc extending to the Tongan border of New Zealand's Exclusive Economic Zone, issued in 2006. The licence covered upwards of 40 sparsely researched seamounts as well as prospective back-arc structural features. A number of located sites had indications of SMS mineralisation (New Zealand Ministry of Economic Development, 2007).

- The southern one-third of the Colville Ridge, a structure considered to be a remnant arc and prospective for older, inactive SMS deposits (New Zealand Ministry of Economic Development, 2007).

7.2.2.4 Trans-Tasman Resources Ltd (TTR)

Trans-Tasman Resources Limited (TTR) was established in September 2007 to explore, assess and develop the rich iron ore deposits (iron sands) off the west coast of the North Island of New Zealand (Trans-Tasman Resources, 2011a).TTR held a prospecting licence which expired in March 2012 and has lodged applications for subsequent Exploration Permits for two offshore areas; between Rangitikei river in the south to the Waikato river in the north (Trans-Tasman Resources, 2011a; New Zealand Ministry of Economic Development, 2012).

TTR also holds a Continental Shelf Act Prospecting Licence for a further 3,314km^2 in New Zealand's Exclusive Economic Zone, which expires at the end of 2014 (Trans-Tasman Resources, 2011a; New Zealand Ministry of Economic Development, 2012).

7.2.2.5 Japan Oil, Gas and Metals National Corp (JOGMEC)

Japan has previously announced plans to use deep-sea mining robots to exploit rare earths and precious metals on the ocean floors around the island nation within a decade (AFP, 2011). The state-backed Japan Oil, Gas and Metals National Corp (JOGMEC) plans to deploy the remote-controlled robots at depths of up to 2,000 metres (AFP, 2011).

The JOGMEC project will focus on seabed volcanoes and hydrothermal vents near the Izu and Ogasawara island chain (Bonin Islands), south of Tokyo, and the southwestern Okinawa islands . The research has uncovered large deposits rich in rare earth elements.

7.2.2.6 Chatham Rock Phosphate Ltd

Chatham Rock Phosphate Ltd holds an exploration licence over an area off the coast of New Zealand believed to have significant seabed deposits of rock phosphate, proposed for extraction and for use as a fertilizer, as well as other potentially valuable minerals. The licence area of 4,276 km^2 is 450 km east of Christchurch, at relatively shallow depths on the Chatham Rise and in New Zealand territory (Chatham Rock Phosphate, 2012). The Licence was granted in 2010 and expires in February 2014 (New Zealand Ministry of Economic Development, 2012).

7.2.2.7 Bluewater Metals Pty Ltd (operating as a subsidiary of SMM Project LLC)

Bluewater Metals (Solomon Islands) Limited was granted a prospecting licence by the Department of Mines and Energy in the Solomon Islands in 2007 to undertake systematic mineral exploration and is interested in prospecting for gold and copper. During a prospective exercise in the Western Province in 2010, seabed copper samples were retrieved.

7.2.2.8 Green Flash Trading

Green Flash Trading of South Africa focuses primarily on the manufacturing, importing and distribution of advanced electrical products and accessories, engaging in the production and sales of these products (Green Flash Trading, 2012). Green Flash Trading has lodged an application to prospect for phosphates offshore of the Western Cape coast, between Adam Se Baai on the West Coast and Table Bay, and off Cape Columbine and Infanta, both near Aghulas. Green Flash has applied for rights to a total of 108 000km^2 (Blaine, 2012a).

The application, lodged in 2012, caused considerable controversy because the prospecting area impinges on South Africa's only Marine Stewardship Council accredited fishery (a hake trawl fishery), which employs 28 000 people and brings an annual R2.8bn. Also, the proposed prospecting area overlapped with areas identified in the National Biodiversity Assessment and Offshore Marine Protected Areas report as being of key biodiversity importance; and yet the potential impacts had not been properly analysed (Blaine, 2012a). Since then Green Flash Trading has been co-operating fully with the World Wide Fund for Nature South Africa (WWF-SA) since the non-governmental organisation lodged an objection to Green Flash's applications to prospect. According to WWF-SA senior marine programme manager Samantha Petersen, Green Flash have agreed to address all of WWF’s concerns (Blaine, 2012a). The outcome in terms of environmental protection, however, remains to be seen.

7.2.2.9 Sandpiper Marine Phosphate Project

The Sandpiper Marine Phosphate Project is located on the Namibian continental shelf approximately 120 km south southwest (SSW) of Walvis Bay . Six Exclusive Prospecting Licences comprise the Sandpiper Project. In June 2011, a Mining Licence was granted, valid for 20 years, covering 2 233km^2 and including all of the mineral resource defined in the Sandpiper Project area (Minemakers Ltd, 2012). The company has stated that its primary objective is to develop a phosphate project in Namibia, initially to supply phosphate (‘rock phosphate’) regionally in Africa and subsequently to the international phosphate markets. The company also states that it intends to undertake this development in a responsible manner, with due and proper consideration to corporate, social, economic, and environmental matters (UCL Resources Ltd, 2012).

7.2.2.10 Northern Manganese Ltd

Northern Manganese Limited acquired 100% of North Manganese Pty Ltd in 2011, an Australian company that has applied for 7 mineral exploration licenses covering approximately 3 856km^2 of shallow marine terrain in close proximity to the Northern Territory mainland. The project, focusing on extensive manganese deposits, is known as the **Blue Mud Bay Project** (Northern Manganese Ltd, 2012a).

All tenements are located over the shallow shelf seas within the north-western side of the Archipelago, off the mainland of the Northern Territory. The marine depths of the tenements in question vary from a couple of meters to a few tens of meters at most. Some small islets within the overall area have been included in the applications (Northern Manganese Ltd, 2012a).

Northern Manganese Limited also holds exploration rights for eight tenements covering 1 723 km^2 of shallow marine terrain and two islands near Groote Eylandt in the Northern Territory of Australia. This project is known as the **Groote Eylandt Project**.

No mining of the Territory's sea bed will be possible, however, until 2015 after the Northern Territory Government announced a temporary ban to allow a comprehensive assessment on the potential impact of sea bed mining by the Environmental Protection Agency (NT News, 2012). This ban does not cover petroleum or gas exploration or production.

7.2.2.11 Fortescue Metals Group

Fortescue Metals Group holds over 500 kilometres of mining tenements in West Australian coastal waters. However, this is under threat as conservation groups call for greater protection of marine life. Mapping analysis shows that the company's proposed exploration sites run extremely close to two zones protected under the federal government's marine reserves network. One site is near Karratha in the Pilbara and the other is north of Broome (Financial Review, 2012).

Fortescue has not said what it intends to do with its coastal tenements, although industry sources say it is probably a potential iron sands play, whereby ore would be extracted from coastal waters. A spokesman for the company has previously said that any exploration would only occur if the company was confident it could be conducted in an environmentally sound manner (Financial Review, 2012).

8. USES OF METALS FROM SEABED MINING

The following list gives the major uses of metals which are/could be extracted from seabed mining operations. What is evident from this list is the vital roles of these products in the electronics and green technology sectors, particular in the production of smartphones, tablets and hybrid vehicles. These are clearly sectors in which efficient design and sustainable production, consumption and takeback/closed-loop recycling will be imperative if current or projected future resource limitations are to be avoided.

8.1 Copper

Preferred metal for electricity production and distribution in products such as building wire, telecommunications cables and circuit board conductors (British Geological Survey, 2007; Goonan, 2009). In the transport sector, copper is used in vehicle brakes, radiators and wiring, whilst copper-nickel alloys are non-corrosive and provide material for the hulls of ships (U.S. Geological Survey, 2012b).

8.2 Silver

Mobile phones, PCs, laptops and batteries currently use the largest volumes of silver, though many of the newer uses of silver focus on its antibacterial properties (Thomson Reuters GFMS, 2011).

8.3 Gold

Gold's primary end use is in jewellery (U.S. Geological Survey, 2012c), though it has also been used extensively in electronics. Base metal-gold alloys are increasingly providing a cheaper alternative to gold in electrical products (U.S. Geological Survey, 2012c).

8.4 Zinc

IPrimarily used for galvanising steel or iron to prevent rusting but is also commonly used as an alloy and in the production of brass and bronze. Zinc oxide is also used in the production of paints and pharmaceutical products (British Geological Survey, 2004).

8.5 Manganese

Used primarily in the construction industry. It is essential to iron and steel making because of its sulphur fixing, deoxidising and alloying properties, as well as its relatively low cost (Geoscience Australia, 2012).

8.6 Cobalt

IPrimarily used in the production of super alloys with resistance to high temperature, such as those used to make aircraft gas turbo engines (U.S. Geological Survey, 2012a). Rechargeable batteries including the lithium-ion batteries used in hybrid electric vehicles also consume high proportions of cobalt as 60 percent of the cathode in lithium-ion batteries is composed of lithium-cobalt oxide (British Geological Survey, 2009).

8.7 The Rare Earths (REEs)

A set of 17 elements including the 15 in the lanthanide series,plus scandium and yttrium (British Geological Survey, 2011). They are used in the widest group of consumer products of any group of elements and have electronic, optical, magnetic and catalytic applications (British Geological Survey, 2011). Trends suggest that "green" – carbon reducing –technologies such as hybrid electric cars, catalytic convertors, wind turbines and energy efficient lighting are key growth areas for REEs (Schüler *et al*., 2011; Ernst & Young, 2011).

9. THE ALTERNATIVE – RE-USE AND RECOVERY OF MINERALS AND METALS

9.1 Introduction

Over the past few decades, an increasing demand for products such as automobiles, mobile phones, televisions and computers have led to pressure on reserves of minerals including rare earths, copper, cobalt and gold (European Commission, 2010). In light of the projected scarcity of these metals, alternatives to the exploitation of virgin stocks must be explored. Alternative strategies that have been proposed include: (i) switching from terrestrial to marine resources, as described in previous chapters on seabed mining;(ii) substituting the metals in short supply for more abundant minerals with similar properties (Department for Environment, Food and Rural Affairs, 2012); and (iii) collecting and recycling the components of products at the end of their life-cycles so that critical minerals are not simply lost to landfill (US Department of Energy, 2012). It is the third option, which also covers issues relating to designing products to facilitate disassembly and introducing strong incentives or requirements for manufacturers to take back end of life products, that represents the most sustainable way ahead to generate metal resources and is easily attainable by society today

9.2 Options for increased recycling & resource efficinecy

The recovery of elements and compounds from waste materials and products has been referred to under the general heading of 'urban mining' (United Nations Environmental Programme, 2011), i.e. the recycling of metals from anthropogenic waste products such as mobile phones, laptops and building materials such as copper pipes. The term is intended to encompass the collection, transportation, separation and recycling of the components in buildings and consumer products at the end of their respective life cycles, though it tends to imply cruder recovery of metals from mixed waste streams**.** 'Urban mining' is seen as a significant opportunity to attain a secondary supply of key materials for which no substitutes are known, while reducing the environmental impacts of mining, and minimising the volume of waste materials entering landfill (US Department of Energy, 2012) or other waste disposal operations.Some metals lend themselves better to recycling than others. For example, 80% of mined copper is still in use today as a result of recycling. This is partly because copper retains 100% of its properties in recycled form and is available in large enough volumes for recycling to be efficient (Holding, 2012). In contrast, the processing involved in extracting minute quantities of rare earth elements from products such as mobile phones and PCs may prove to be less fruitful (Schüler *et al.,* 2011). A large enough quantity of consumer products and more effective product disassembly is essential if the recycling volumes of rare earths are to increase significantly (United Nations Environmental Programme, 2012).

9.3 Social and environmental issues surrounding product recycling and 'urban mining'

Many obsolete electrical products still contain significant quantities of a number of hazardous substances such as lead, mercury, cadmium and chromium, as well as flame retardants in plastics and resins (Parliamentary Office of Science and Technology, 2007; Achillas *et al*., 2010; Chan and Wong, 2012; European Environment Agency, 2012). During the disassembly and recycling processes, these hazardous materials must be extracted safely. Recycling must therefore be carried out in a controlled environment and using techniques and equipment which can ensure that workers are not exposed to hazardous substances and hazardous wastes are not released to the environment. In parts of the world where regulatory controls of e-waste recycling are poor or lacking, workers and others in the affected communities can be exposed to high levels of hazardous chemicals in air, dust and soot, among other sources, putting their health at risk. Furthermore, the surrounding environment can become polluted which can pose a risk to people and wildlife over larger areas (Brigden *et al.* 2005, Walters & Santillo 2008, Labunska *et al.* 2013).

Environmental organisations are concerned about the illegal export of e-waste (including Waste Electronic and Electrical Equipment (WEEEs) containing hazardous substances) from the EU to developing countries, where environmental health standards are all too often lax or not properly policed (Parliamentary Office of Science and Technology, 2007). For example. over 100,000 tonnes of waste electrical and electronic equipment were exported from Europe to West African nations during 2007 (European Environment Agency, 2012).

9.4 Barriers to safe and effective takeback and recycling

Despite the apparent benefits of proper separation, take-back and recycling, a number of factors currently prevent electronic goods from being recycled in high volumes. First, few electrical products are designed for effective disassembly, inhibiting the removal of the valuable components at the end of the product life cycle (Schüler *et al*., 2011; US Department of Energy, 2012). This is particularly true for metals used in minute quantities, such as rare earths (National Risk Management Research Laboratory, 2012). Improving the design of products for easier disassembly would facilitate efficient recycling (US Department of Energy, 2012).

There is also, in many parts of the world, a lack of infrastructure to collect electrical products from consumers when they no longer use them, reducing the volume of goods that reach recycling centres, particularly in developing countries (Reck and Graedel, 2012).

9.5 How are these issues being addressed?

9.5.1 *Policies*

In Europe, the EU WEEE Directive was introduced in 2007 to help reduce the levels of WEEE being consigned to landfill and to encourage resource efficiency through recycling and reuse. The directive sets out measures for the collection, treatment, recovery and recycling of all electrical and electronic products (Parliamentary Office of Science and Technology, 2007; Barba-Gutiérrez *et al.,* 2008; Department for Environment, Food and Rural Affairs, 2012).

In Japan, the Home Appliance Recycling Law (HARL) came into force in 2001 to put targets on the percentage of consumer appliances that should be recycled each year. The law has been effective at increasing volumes of recycling (DTI, 2005).

9.5.1 *Producer Responsibility*

Under the EU WEEE directive, manufacturers are responsible for their products at the end of their useful life (Parliamentary Office of Science and Technology, 2007). It is hoped that this will encourage manufacturers to design products with longer life spans, ones that are easier to disassemble and recycle at the end of their lifespan, which generate less waste, and which contain fewer critical or hazardous materials (Parliamentary Office of Science and Technology, 2007).

Incentives and take back schemes operate in many countries. One success story has been Dell's scheme in the United States. The company offers to collect and recycle computers from personal users and businesses alike. It collected 44 million kilograms of IT equipment in 2009, the highest volume of any take-back scheme (Electronics Take Back Coalition, 2010). The success of the scheme has largely been attributed to the large number of collection points, with 2 490 distributed across the USA, often in branches of other stores (Electronics Take Back Coalition, 2010).

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