Blue Growth

Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts

Marine Sub-Function Profile Report
Marine Mineral Resources (3.6)

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The research for this profile report was carried out in the period April – August 2011. This report has served as an input to the main study findings and these have been validated by an Expert meeting held on 9/10th November 2011 in Brussels. The current report serves as a background to the Final Report on Blue Growth.

Content

1 State of Play

Increased scarcity and competition for raw materials have brought man to search for treasures in unexpected places. The oceans are thought to hold massive amounts of valuable minerals such as gold, copper, and cobalt. A price surge in raw materials, security of supply to critical minerals, technological developments and new discoveries of mineral deposits have spurred a revived interest in mining the oceans.

Attempts to harvest so called manganese modules were made already in the 1970s. Several countries including Germany, US and France engaged in search expeditions but in 1984, after nearly 15 years of trying and millions of Euros spent, the attempts were discontinued due to meagre results. Today's situation is different as technologies are more developed and a strong legal framework has been set up under UNCLOS. Moreover, the renewed search has shifted from manganese nodules to hydrothermal vents which are expected to be easier to locate and contain more raw materials.

Exploitation and mining are still on a nascent stage. Only one mining project, the Solwara 1 off the coast of Papua New Guinea, is scheduled to begin in 2013. Nevertheless, international interest is growing rapidly and both Russia and China recently applied and received exploitations rights on international waters. Important question marks remains: how big are the deposits, how do we get them up, and what are the environmental consequences of deep-sea mining?

The next parts of chapter one includes a technical description of the deep-sea mineral resources and their location; an overview of the value-chain; the regulatory environment; and, the strengths and weaknesses of the sub-function.

1.1 Description of deep-sea mining

Marine mineral resources in this thematic paper are understood as all raw materials found on and under the seabed, excluding fossil fuels (oil, gas and methane hydrates), phosphorates, and renewable energy sources such as seafloor hot-springs. The paper also excludes aggregate mineral resources such as sand, gravel and crushed rock.

1.1.1 Technical description and location of marine mineral resources

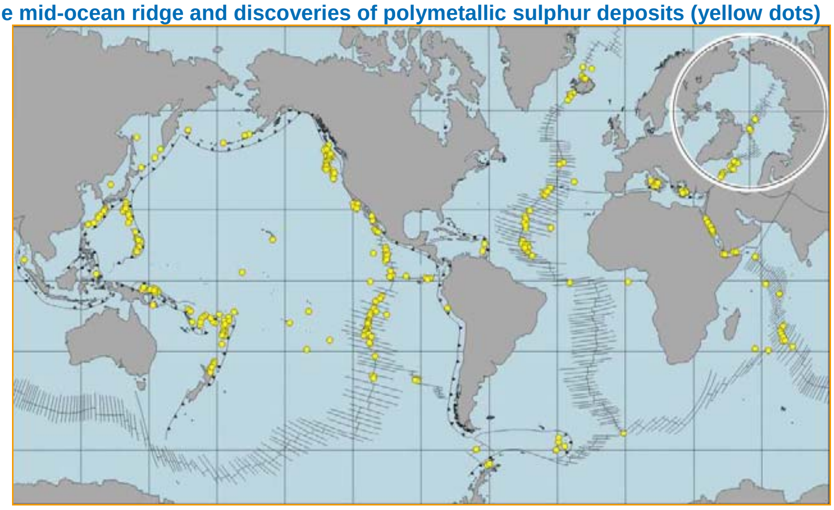
The deposits of marine minerals can be divided into three categories: (1) polymetallic sulphurs, (2) ferromanagenese crusts, (3) (ferro) manganese nodules, and (4) rare earth elements and yttrium, and. They differ in composition, shape and location.

Polymetallic sulphides

Deep-sea polymetallic sulphide deposits are created when sea-water seeps through the sea-floor and reaches hot magma and reacts with the surrounding rocks. Due to temperature rise, pressure increases until the hot fluid discharges through fractures (vents) between the tectonic plates. When the hot fluid reaches the cold sea water it precipitates over the sea-floor. The mineral and metal rich discharge takes different shapes and sometimes form chimneys (also called “black smokers”) or dome formations. The accumulated deposits can contain large amounts of possibly millions of tonnes of high-grade ore (Halfar and Fujita, 2002).

The spread of polymetallic sulphides are generally connected to the mid-ocean ridge which is an underwater mountain range running across the globe. The ridge marks the delineation between two tectonic plates and is typically characterised by a valley with high volcanic activity. Since polymetallic sulphides develop through reactions between sea-water seepage through the earth's crust, it is natural that most mineral deposits have been found across the ridge.

Figure 1 the mid-ocean ridge and discoveries of polymetallic sulphur deposits (yellow dots)



Source: Petersen, S. (2011) Modern Seafloor Massive Sulfide Deposits: Challenges and Opportunities. IFM-GEOMAR, Presentation to Marine Geosciences and Geotechnology Santos, February 14.-16. 2011.

The mid-ocean range contains approximately 50.000 – 100.000 black smokers if one assumes one smoker at every kilometre (Petersen, 2011).

The largest polymetallic sulphide deposit known is the Atlantis II Deep situated in the Red Sea between Saudi Arabia and Sudan (Bertram et al, 2011). It contains high concentrations of metals including zinc, copper, silver and gold. The Government of Sudan supported by the Saudi-Sudanese Red Sea Commission has partly explored the deep as well as pre-processing mined sediments (Bertram et al, 2011). The Saudi company Manafa has been given exclusive exploitation rights and early estimations valuates the deposits to 3.11 billion to 5.29 billion (copper, zinc, silver and gold) and with an additional 2.6 – 2.9 billion for manganese and cobalt extraction (Bertram et al, 2011).

The first mining operation for polymetallic sulphides is the Solwara 1 project at 1600 meters depth in the Bismark Sea, Papua New Guinea. The company, Nautilus Minerals Inc has exploitation rights and plans to start excavation in 2013, mainly for copper and gold.

Important terminology

- Polymetallic Sulphides (also called Seafloor Massive Sulphides) – metal sulphides formed on the seabed from minerals dissolved in superheated waters on the seabed from minerals dissolved in superheated water near subsea volcanic areas. They commonly contain copper, lead, zinc, and other minerals;
- Ferromanganese Crusts – cobalt-rich manganese crusts formed as pavements on the seafloor on the flanks of seamounts, ridges, and plateaus in the Pacific region. They may also contain lesser amounts of other metals such as copper, nickel, etc.
- Ferromanganese Nodules – similar in composition to ferromanganese crusts, but in the form of small potato-like nodules scattered randomly on the surface of the seafloor. Those found within the EEZ in the

Atlantic Ocean tend to be lower in cobalt content than deep ocean manganese nodules in the Pacific Ocean.[1]

- Hydrothermal vents – an opening (fracture) in the earth's crust at tectonic plate boundaries. It releases hot fluid with high mineral content.
- "Black" and "White" Smokers – Smokers are the exits in the shape of chimneys of hydrothermal vents which spew out hot mineral rich water. The release from black smokers could reach 400º and normally contains iron and sulphides. The white smokers are cooler and contain other materials such as barium, calcium, and silicon.

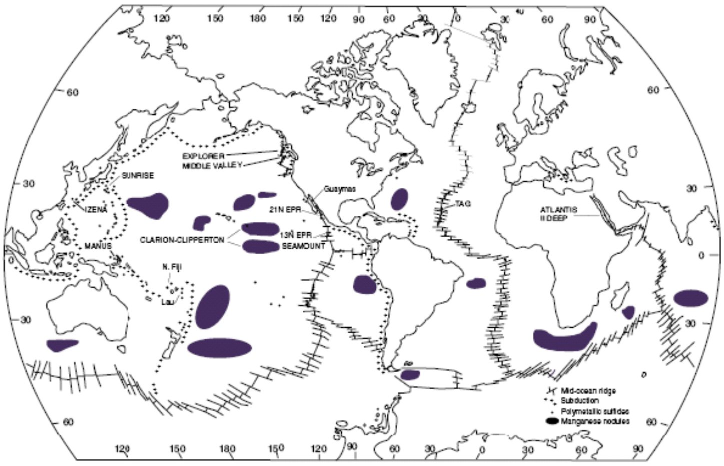
Ferromanganese crust

The cobalt-rich crust is formed at 1000 – 3000 m depth on the flanks and summits of seamounts, often volcanic areas in the EEZs of island states of the South Pacific (Maribus, 2010). The crusts have similarities with nodules in that they are formed while metals slowly are dissolved in water and contain mainly cobalt but also iron, manganese, nickel, platinum and other metals (ISA, 2004). Ferromanganese crusts, however, are not spread over the sea-floor plains, like manganese nodules, but rather formed in areas with volcanic activity (Ibid.). The crusts are often situated in areas with steep angles and rugged bottom which makes excavation particularly challenging.

Manganese nodules

Polymetallic nodules or ferromanganese nodules became the first discoveries to generate considerable interest in mining the oceans (U.S. Congress - OTA, 1987). The nodules are potato-shaped lumps with sizes ranging from a few millimetres to over 10 cm. They are spread out over the so called abyssal plains all over the ocean floor at about 4500 – 5500 meters depth (Scott et al, 2008).[2] The number of nodules was first estimated to 1.5 trillion tonnes by J.L. Merlo and later reduced to 500 billion tonnes by A.A. Archer (ISA, 2006a). However, the number of commercially interesting nodules is far from all and the aggregate value is methodologically difficult to calculate. The process of nodule formation is still not completely understood (ISA, 2006a).

Figure 2 Distribution of manganese nodules (and some polymetallic sulphurs)



Source: Scott, S. et al (2008) Mineral Deposits in the Sea: Second Report of the ECOR Panel on Marine Mining (September 2008). (http://www.oceanicresources.org/specialist-panels/ecor-2006-symposium-panel-working-group-reports/)

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[1] The first three bullet-points have been adapted from: U.S. Congress, Office of Technology Assessment (1987)

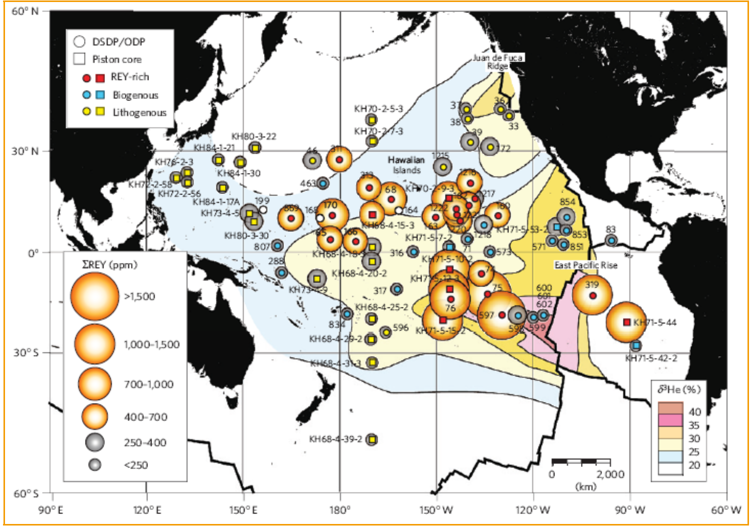
[2] Note that private exploration parties, such as Nautilus Inc. claims to have discovered manganese-nodules at a 2000 m depth which makes the operation more commercially viable (Mining Magazine, 2005).

The most prospective findings of all seep-sea minerals are located in the Pacific and in particular around the tectonic plate boundaries. Whereas nodules have enjoyed the most interest over the last decades, companies and governments have switched to polymetallic sulphurs. The Japanese findings of rare earth elements and yttrium were only reported on recently and further exploration will assess the exact locations, size and quality.

Rare earths

Recent studies have shown large potentials of rare earths and yttrium to be found in sea-floor sediments (mud). At depths down to 50 meters below the seafloor, a Japanese research team has estimated that the sea-floor can contain more than all the rare earths buried on land (Kato et al, 2011). In certain hotspots, one square kilometre is estimated to contain 25,000 tonnes of rare earths (Jones, 2011). The survey has been made in the Pacific and found particularly large deposits around Hawaii:

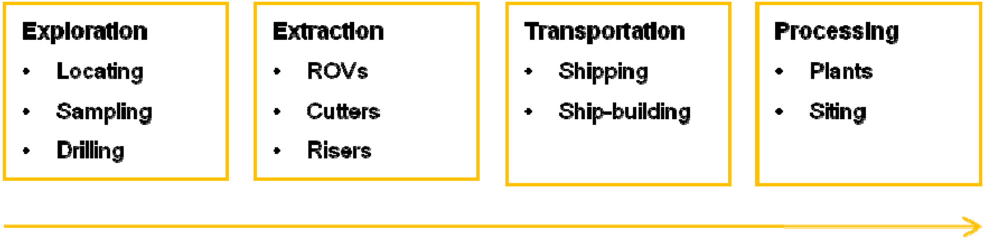
Figure 3 Distribution of samples containing REY (Rare earths and Yttrium)



Source: Kato et al (2011) Deep-sea mud in the Pacific Ocean as a potential resource for rare-earth elements. Nature Geoscience: Letters, NGEO 1185

1.1.2 The value-chain

Figure 4 Value-chain of deep-sea mining



Source: Based on Birney et al. (2006)

The value-chain of deep-sea mining consists of four main steps:

1. In the **Exploration phase**, different techniques for locating and testing ore content and quality is carried out through locating, sampling and drilling,
2. In the **Extraction phase**, ROVs, cutters and risers are used to carry the ore from the bottom up to the surface,
3. In the **Transportation phase**, shipping and ship-building is in focus; and finally,

4. In the **Processing phase**, the extraction of minerals in plants is carried out. Here also the site plays a key role.

Exploration

In the exploration phase, different techniques are used to locate mineral deposits. To find manganese nodules multibeam echo sounders (side-sonars) this enables near real time “reading” of bottom strips (ISA, 2006a). The strips are assembled with GPS to create an aggregate picture. Side-sonar is complemented with deep-tow sonars which are pulled along the sea-bed to collect samples and pictures.

Extraction

To date, no excavation of solid minerals has taken place beyond 200 meters below sea-surface (ISA, 2006c). Samples of nodules, polymetallic sulphurs, and rare earth minerals are taken at depths from 2000 – 5500 m. Clearly, the technical challenge of carrying out large-scale mining operations at those depths presents real challenges. A key technology is the Remotely Operated Vehicles (ROVs) which has been used to dig trenches for cables on the sea-floor, which are expected to cut and lift pieces of the mineral deposits. The sludge then needs to be vacuumed and pumped up to carriers at the surface. The main difference from the earlier versions of ROVs used at depth of 500 meter or less in oil and gas exploration, is that the mineral deposits are positioned at 2000-5500 m depth (McLeod, 2008).

Transport

Transport of possibly thousands of tonnes of ore to processing plants will be crucial in deep-sea mining, in particular when deposits on international waters are explored. Hayden (2004), for example, argues that price for shipping will be a key condition for where mining activities will first take place. The only known vessel under construction to cater to the specific needs of deep-sea mining is built by the Kiel-based ship-yard Harren and Partners in Germany (Reuters, 2011). At €127 million, the vessel constitutes a major budget post in deep-sea mining ventures.

Processing

Due to the large quantities of ore, processing will take place on-shore (Hayden, 2004). Several techniques for processing manganese nodules have been suggested. In general two techniques have been tested: hydrometallurgy, where the metals are separated with acids (hydrochloric or sulphuric) or basic reagents (ammonia), and smelting (ISA, 2006a).

1.2 Market structure

Only a limited number of companies are exclusively dealing with sub-sea mining, however, many of those already involved in oil and gas exploration and extraction have launched innovation initiatives and follows the developments closely. To date, the only company which has far reaching plans to start extraction is Nautilius Minerals, Inc (including subsidiaries). Nevertheless, European companies have built up a considerable experience and expertise in the adjacent technologies mainly used in oil and gas exploitation:

Table 1 (Non-exhaustive) Overview of companies involved in deep-sea mining

Company	Main activity	Country	Comment
Nautilus Minerals, Inc.	Exploration	UK/US	http://www.nautilusminerals.com/s/Home.asp
Neptune Minerals, Inc.	Exploration	Canada	http://www.neptuneminerals.com/
Manafa	Exploration/ Extraction	Saudi-Arabia	http://www.manafa.com/about.html
Technip	Exploration/ Extraction	France	
Bluewater Metals South Pacific Inc	Exploration	Australia	Operates as a subsidiary of SMM Project LLC
United Nickel Inc.	Exploration	Canada	Operates as subsidiary to Nautilus Minerals
Nauru Ocean Resources	Exploration	Nauru	Subsidiary of Nautilus Minerals
IHC Merwede	Extraction/Transport	Netherlands	
Harren & Partner	Transport	Germany	Nautilus has commissioned Harren & Partner to build a ship supporting their operations in the Pacific
Voest-Alpine Bergtechnik	Extraction	Germany	Subsidiary of Swedish company Sandvik
SMS Siemag	Extraction	Germany	
Subsea Minerals	Extraction	UK	Carrying out projects for De Beers diamond explorations in Namibia
Soil Machine Dynamics	Extraction	UK	
Fugro Seacore Mining Ltd.	Extraction	UK	Part of Fugro group, once part of Subsea Minerals

Sources: Jarowinsky, Michael (2009), Thakur (2011) and Ecorys.

1.3 Regulatory environment

1.3.1 European objectives and legislation

Over the last few years the EU has formulated several policy documents which identify the need to sustain a secure supply of raw materials. These initiatives help to drive the search for alternatives to land-based sources of minerals. The general approach is built on three pillars:

1. Fair and sustainable supply of raw materials from international markets;
2. Fostering sustainable supply within the EU; and,
3. Boosting resource efficiency and promote recycling.

The following pieces of policy-documents are of interest:

- The raw materials initiative – meeting our critical needs for growth and jobs in Europe (COM (2008) 699), sets out an integrated strategy to secure supply of raw materials, including trade.
- Tackling the challenges in commodity markets on raw materials (COM(2011) 25)

For the actual mining, however, EU is bound to international legislation and deposits are often outside the judicial reach of EU countries.

1.3.2 International legal framework

Exploitation of the sea-floor is governed by the United Nations Convention on the Law of the sea (UNCLOS). It was adopted in 1982 and ratified in 1994 and sets out the legal regime for the Economic Exclusive Zones (EEZs) of countries and the internationals waters beyond the EEZs. EEZs constitute the maritime territory where nation states have exclusive exploitation rights for resources. It stretches 200 nautical miles (370km) from the coast-line. For international waters, any exploitation must receive authorisation from the International Seabed Authority (ISA) based in Kingston, Jamaica. Both companies (sponsored by states) and countries can apply for concessional rights. In 2000 the ISA adopted regulation for exploration of polymetallic nodules and is since 2002 busy preparing a regulation for cobalt-rich ferromanganese crusts.

Most mining activities and exploration takes place under the EEZs. Mining is here carried out on more shallow water, transportation of ore is considerably shorter, and the administration time for concession rights is generally shorter than on international waters. Hence, to date licences for exploration and extraction has taken place bilaterally between companies (mainly Nautilus Minerals Inc.) and coastal states mainly in the Pacific.

On international waters however, recent developments have displayed the unprecedented interest in exploration and extraction licences. On May the 25th, 2010, China filed an historical application to the ISA. The Chinese Ocean Mineral Resources Research and Development Association (COMRA) want to explore the Southwest Indian Ocean Ridge for polymetallic sulphides (ISA 2010a). The event marked a first-of-a-kind attempt to explore the deep sea bed on international waters. Only weeks earlier, the ISA adopted a draft regulation, which after six years of negotiations became the first step towards development of a comprehensive set of rules, regulations and procedures to govern prospecting, exploration and exploitation of marine minerals (ISA 2010b). The Chinese was followed by Russia filing a similar application in January 2011 (ISA 2011). 19 July 2011, in the seventeenth session of the ISA, four applications were adopted, among them the Chinese and the Russian. Two other entities received clearance; Nauru Ocean Resources Inc. (NORI), sponsored by Nauru, and Tonga Offshore Mining Limited (TOML), sponsored by Tonga. They submitted their applications on 31 March 2008 for exploration for nodules in the reserved Area of the Clarion-Clipperton Fractured Zone (ISA, 2011b).

1.4 Strengths and weaknesses of deep sea mining

1.4.1 Strengths of deep-sea mining

- Early estimations of deposits in, ferromanagese nodules, polymetallic sulphides, ferromanganese crusts and rare earth and yttrium, could potentially supply global manufacturing with large amounts of copper, cobalt, nickel, zinc, rare earth elements and several other resources. Currently, several of these, such as copper, have experienced a surge in price since the emerging economies in, for example, China and India have increased manufacturing manifold.
- Several modern technologies such as batteries for hybrid cars, windmills, super-magnets and smart phones are heavily dependent on rare earths. Land based extraction of rare earths is heavily concentrated to China (97%) which has capped export as a measure to protect the domestic market. Hence, innovation and development of new technologies benefits from a secure flow of rare earths.
- European companies are world leaders in adjacent technologies such as dredging, drilling, cutting, transport and ROVs, which will be essential in case large scale mining takes off.
- There is an international legal framework for regulating mining on international waters. Bilateral agreements between companies and coastal states are already in place. The legal situation reduces uncertainties for investors with long-term planning.

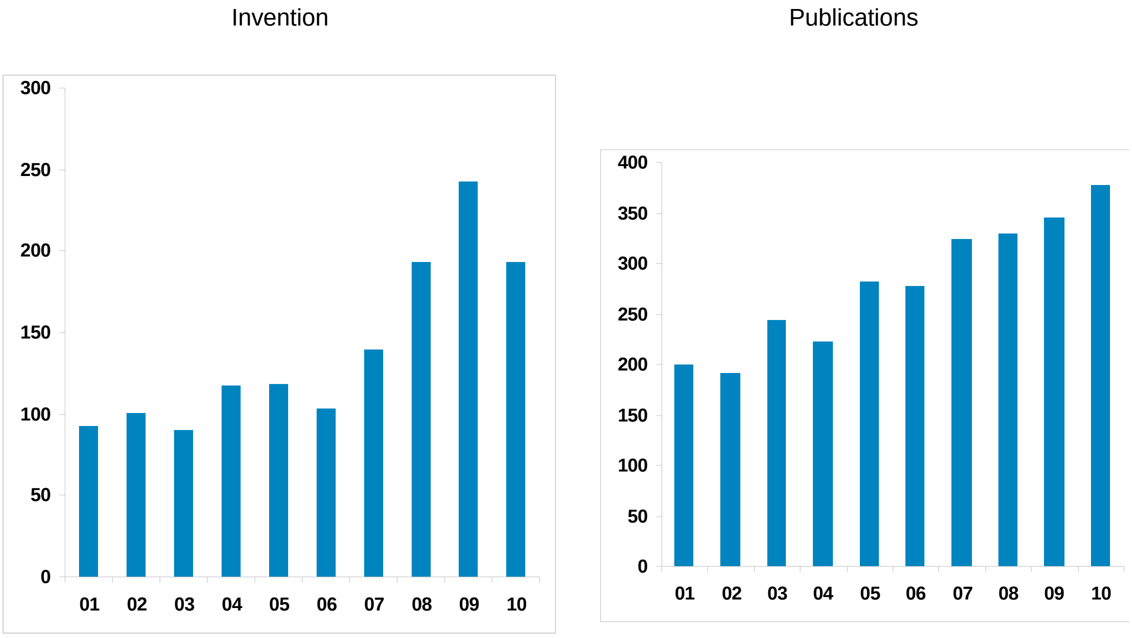
1.4.2 Weakness of deep-sea mining

- It is still highly uncertain how much of the deposits that can be commercially exploited. The interest and attempts to mine the sea-bed are not new and new projects have yet to prove commercial viability.
- Large uncertainties remain whether the technological capabilities exists to embark on commercially viable large-scale operations.
- There are considerable environmental concerns and uncertainties what it means to disturb deep-sea eco-systems on a large scale. Operations on the sea-floor may destroy unique habitats and seriously disturb the flora and fauna of the deep-seas.
- The effects of mining on the ecosystems are difficult or even near impossible to predict. For individual hydrothermal-vents the recovery could be quick and already abundant species are expected to come back within a few years (Van Dover, 2011). For more rare species, the impacts are probably more severe. The cumulative effects on a larger area are more difficult to predict (Van Dover, 2011). For mining of manganese nodules the environmental impacts are even more uncertain. Clearly the technique used for mining determines the effects of, for example, sediment plumes and chemical use, however the biological effects from the removal of nodules from the sea-bed are unknown (Horst et al, 2001).
- Coastal communities in trial regions, in for example Papua New Guinea, are worried about the impact on fisheries and corals (Shaffner, 2008). In a worst-case scenario negative impacts may include large losses of species and primary production, degradation of habitats, and pollution (Van Dover, 2011).
- Land-based processing demands high energy input and the use of chemicals, which has troubled the affected regions before in connection with conventional mining.

2 Research and technology

2.1 Research & technology mining patterns

Table 2: Total number of global inventions and publications related to Marine Mineral Resources (2001 – 2010)



Invention

Publications

Source: Thomson Reuters

The rising number of global inventions in the past two years and more so of the publications in the course of the last decade gives a clear outlook of the increasing importance of Research and Technology in this function.

The table below compares EU-27 countries in terms of patents filed on their grounds, with competing countries (2001–2010). Priority country means the place where the invention was invented and filed. 3

Table 3: Country score in inventions related to Marine Mineral Resources

Priority countries	Total inventions (2001 - 2011)	% of global
US	424	19%
EU-27	361	16%
China	339	15%
Japan	336	15%
South Korea	196	9%
Global	2248	

Source: Thomson Reuters

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[3] Priority country is used in the absence of an inventor county within the patent data. The particular field is not present across a good amount of authorities

Figures above indicate that the US is leading in terms of inventions, with 19 % of global inventions tightly followed by the EU-27 with 16%.

Table 4: Country score in scientific citations related to Marine Mineral Resources

Priority countries	Total citations (2001 - 2011)	% of global
EU-27	7348	37%
US	2943	15%
China	1559	8%
Japan	1076	5%
South Korea	262	1%
Global	19861	

Source: Thomson Reuters

Table 5: Country score in published papers related to Marine Mineral Resources

Priority countries	Total published papers (2001 - 2011	% of global
EU-27	1169	31%
US	591	16%
China	376	10%
Japan	227	6%
South Korea	86	2%
Global	3763	

Source: Thomson Reuters

Similar to observations for other subfunctions in terms of research and technology mining patterns, the EU-27 is ahead of the field of scientific and of published papers. Since published papers and scientific citations can be considered a certain indicator for future inventions, the table above can be also interpreted as a comparable sound basis for future growth.

Table 6: Top 20 global patent assignees - organizations or individual owners of the patent's invention - are presented in the table below in Marine Mineral Resources

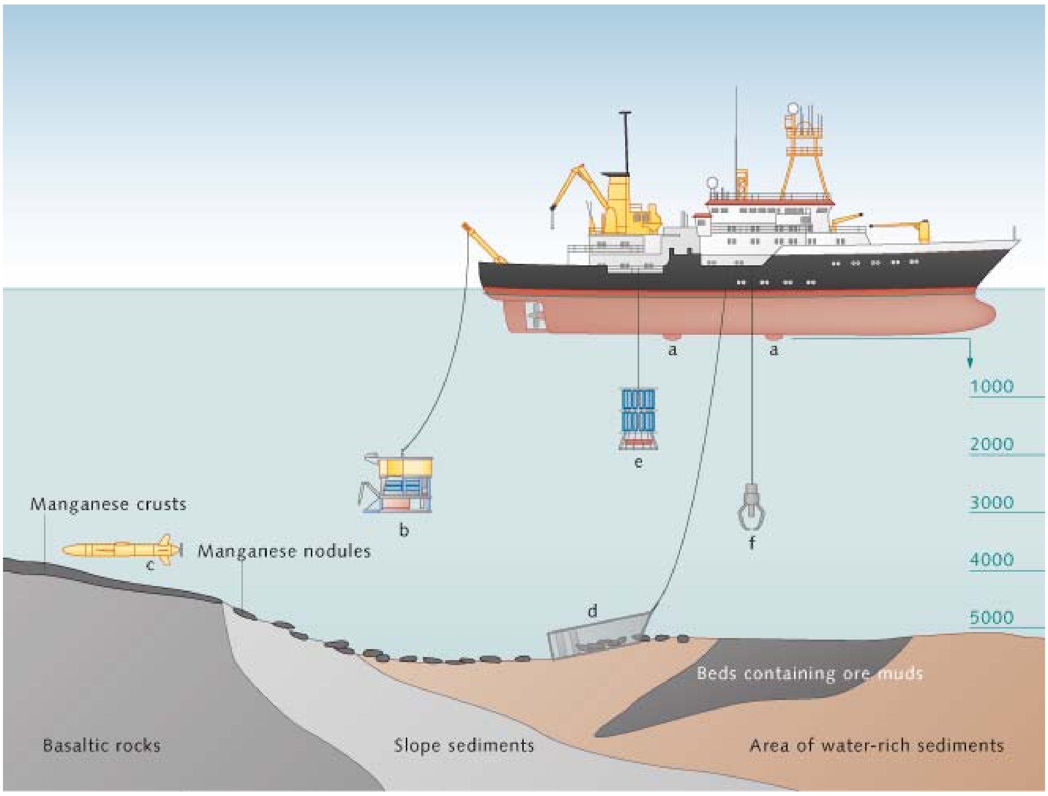
Top assignees	Total number of patents filed (2001- 2011)
L'OREAL SA	15
ST PETERSBURG PLEKHANOV MINING INST	13
CHINESE ACADEMY OF SCIENCES	10
KOSE KK	10
COGNIS CORP	9
ELAN CORP PLC	9
BEIERSDORF AG	8
ABB GROUP	7
BASF	7
CAMERON INT CORP	7
M-I LLC	7
UNIV FAR E TECH	7
BAKER HUGHES INC	6
KAO CORP	6
KIGAM KOREA INST GEOSCIENCE&MINERAL	6
SCHLUMBERGER TECHNOLOGY CORP	6
AKAHO KASEI KK	5
CHINA NAT OFFSHORE OIL CORP	5
COLGATE PALMOLIVE CO	5
LIPOTEC SA	5

Source: Thomson Reuters

With a great number of companies (assignees) based in the EU-27, Marine Mineral Resources can be considered a market where EU companies are rather well represented in comparison to the relative scientific output – publications and scientific citations - of EU research institutes.

2.2 Technological developments explained

The World Ocean Review 2010 presents a schematic overview of the technologies expected to be relevant for the different types of mineral deposits and currently used in the exploration phase:

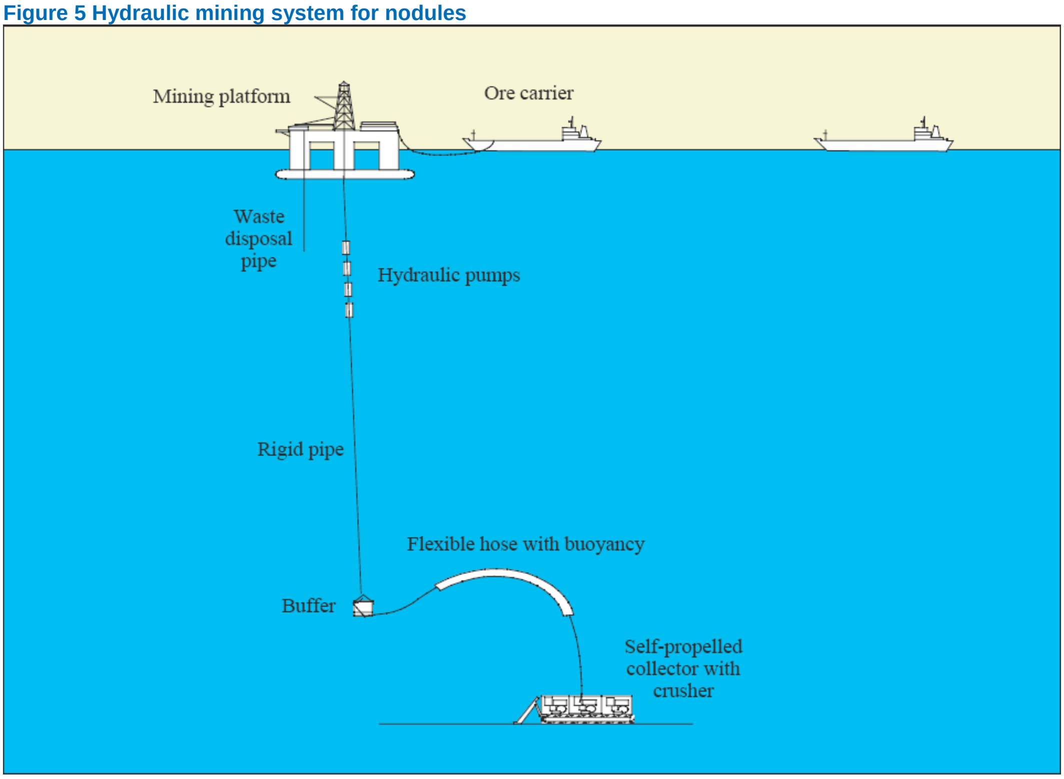


a) Depth profile using echo-sounder; b)ROVs for sampling and image taking; c) AUVs to take samples, echo, and pictures at the sea-floor; d) Large net construction to take samples by dredging the sea-floor; e) Multirosettes to take water samples at different depths; f) Grab arm to take individual samples (Maribus, 2010).

The technologies for exploration have benefitted from several decades of research related technology innovation. The oil and gas industry's rapid development has also brought us to a stage where the bottom of the seas can be explored and sampled in most environments and depths.

In the excavation phase, the technology for mining is more underdeveloped and depends on the type of deposit. For nodules, previous attempts to harvest the sea-floor have brought some innovative ideas. The systems have never, however, been able to yield substantial results. The hydraulic mining system has been suggested as a way forward:

Figure 5 Hydraulic mining system for nodules



Source: ISA, 2006b

More technological challenges exist when mining in crusts and vents which are embedded in the sea-floor. The depth and size of ore deposits puts immense pressures on machines. First one needs an autonomous vehicle (ROV) which cuts the sea-bed (for ferromanganese crust and polymetallic sulphurs). Then, depending on type and location of the deposit, the ROV need to cope with extreme depths and varying undulation slopes. The riser, which transport the slurry excavated by the ROV, is put under extreme pressure from the depth, weight of the ore, and underwater currents. Then, the operations vessel must remain stable in a fixed position in order to support the sub-surface vehicles. Finally, the large amounts of ore needs to be transported to treatment facilities, which in some cases demands large distances on demanding seas to be covered.

A key difference in today’s situation compared to 30 years ago is the large progress made in technology, primarily in the gas and oil industry. European companies have become world leaders in dredging, drilling, shipping, ROVs, transport and cutters.

It is clear that the development of technologies for deep-sea mining will be essential for large-scale projects. Several European Public-Private Partnerships (PPPs) are ongoing, mainly in Germany and France, to support domestic companies.

- In France, for example the government launched a partnership with a number of organisations including Technip, IFREMER and Areva to explore the polymetallic sulphides in theEEZs of *outré mer* islands of Wallis and Futuna. The expeditions are part of the French government’s Grenelle de la Mer policy and aims map the oceans in terms of biodiversity and minerals for possible excavation and to support French maritime technology (Grenelle de la Mer, 2010).
- In Kiel, Germany, the Kiel Cluster of Excellence “The Future Oceans” has built up considerable knowledge and know-how on marine mineral resource. The cluster is a partnership between Kiel Liebnitz Institute of Marine Sciences (IFM-GEOMAR), The Kiel Institute for the World

Economy and the Muthesius Academy of Fine arts. It is funded by the German Research Foundation until, at least, late 2011.[4]

There are several company initiatives which bring together stakeholders, for example:
- OceanflORE is a Dutch - Belgian joint venture between IHC Merwede and DEME which started in 2011. The venture aims to make offshore mining “possible, profitable and sustainable” by acting as an interface between mine owners, financial markets, competent authorities and technology providers.

European initiatives are limited to more comprehensive studies, for example:
- The FP7 project The Deep Sea & Sub-Seafloor Frontier (DS³F) is led by the University of Bremen in cooperation with eight other research institutes. The €1.16 million project aims to provide scenarios and pathways to a sustainable use of the oceans. Marine mineral materials are one of the aspects investigated.[5]

In many of the key technologies, European companies are world leading. In dredging, for example, IHC Merwede takes up 50% of the world market.[6]

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[4] http://www.ozean-der-zukunft.de/english/the-network/the-cluster/overview/

[5] CORDIS (2011) http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=384&CAT=PROJ&QUERY=011df61b4e6a:14bb:73933ea8&RCN=93532

[6] Interview with IHC Merwede, 26 July 2011

3 Future developments

Table 2 gives an overview of the status and characteristics of the marine raw materials believed to be of interest:

Table 2 Commodities by type, location, mining status and economic potentials

Commodity	Type	Location	Mining Status	Economic interest/growth potential
Cobalt	Deep sea nodules	Deep sea	Non-operational	Moderate
Cobalt	Manganese crusts	Intraplate seamounts	Non-operational	Low
Copper	Deep sea nodules	Deep sea	Non-operational	Moderate
Copper	Polymetallic sulphides	Mid-ocean ridge	Non-operational	High
Gold	Polymetallic sulphides	Mid-ocean ridge	Non-operational	High
Lead	Polymetallic sulphides	Mid-ocean ridge	Non-operational	High
Nickel	Deep sea nodules	Deep sea	Non-operational	Moderate
Nickel	Manganese crusts	Intraplate seamounts	Non-operational	Low
Platinum group metals	Manganese crusts	Intraplate seamounts	Non-operational	Low
Rare earth elements	Manganese crusts	Intraplate seamounts	Non-operational	Low
Rare earth and Yttrium	Abyssal plains	Deep sea	Non-operational	Moderate
Silver	Polymetallic sulphides	Mid-ocean ridge	Non-operational	High
Zinc	Polymetallic sulphides	Mid-ocean ridge	Non-operational	High

Sources: EC 2007; Scott, 2008; Kato et al. 2011

There are clearly high potential for marine mineral resources to support a secure supply to the raw materials industry in Europe and for Europe to play an active part in developing technology for exploration and extraction.

3.1 External drivers and conditions/barriers

There are four key drivers which determine the future of marine mineral resources: price of raw materials, technology, politics, and new discoveries. There are also three conditions/barriers affecting the performance of the cluster.

Drivers	Conditions/Barriers
Price of raw materials	Financial risks
Technological developments	Environmental concerns
Political ambition	Legal framework
New discoveries	

3.1.1 *Price of raw materials*

Between 2000 and 2010, prices for raw materials grew the quickest of all primary commodity groups (WTO, 2010). The main reason for the price hike is the emerging economies, such as China, India and Brazil, which consume vast amounts of resources to sustain the near exponential growth in production. The recent economic crisis somewhat dampened the increase, however, the economic rebound has been strong and commodity markets again show record price levels:

Export prices of metals 2000 - 2010 (annual change in %)

	2008	*2009*	***2010***	*2000-10*	*2005-10*
Metals	28	-30	**26**	13	15

Source: WTO (2010)

The main driver for further exploitation is the prices for raw materials on the global markets.

3.1.2 *Technological drivers*

Deep-sea drilling techniques and exploration in the oil and gas industry has made advances in technology which enables improved surveying of minerals. However, large gaps in understanding and technologies still remain. Excavation, for example, is still in its infancy. Problems remain with erosion to pipes from rocks and sand, which is different from gas and oil (Denegre, 2011). Nevertheless, large technological breakthroughs are not expected (or needed) to start the mining.

3.1.3 *Political drivers*

Europe was once self-sustaining in ore-production and metals. Over the last century, however, developments have led the large majority of European producers to import their minerals and metals from non-European producers. A few European countries continues to be large producers of, for example, titanium (Norway), chromium (Turkey) and silver (Poland), however, European domestic mining is in general minor (BGS, 2010). [7]

Metal	% World	EU-32 Countries with >1% of world output in 2008
Chromium	10.7	Turkey (8.1%), Finland
Silver	8.5	Poland (5.4%), Sweden, Turkey
Zinc	7.7	Ireland (3.4%), Sweden, Poland
Titanium	7.1	Norway (7.1%)
Lead	6.6	Sweden (1.6%) Poland, Ireland, Macedonia
Copper	5.1	Poland (2.8%)
Tungsten	3.7	Austria (2%) Portugal
Nickel	3	Greece (1.2%)
Mercury	3	Finland (3%)
Aluminium	1.8	Greece (1%)
Iron	1.4	Sweden (1.1%)
Gold	1.2	---
Manganese	0.3	---

Source: BSG (2010)

European industry is hence heavily reliant on imports of materials. Additionally, a number of critical minerals and metals are heavily concentrated to a few countries. Some of these countries have taken measures to ensure supply for domestic industry (EC, 2011).

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[7] EU-27 + Norway, Croatia, Turkey, Switzerland and Macedonia.

A telling example on the effects of the concentration of raw material stocks and supply comes from a recent cut in export quotas of rare earth from China. China holds 97 % of world production in rare earths and a third of the stock. 95 % of the world's rare earth export is held by China of which half goes to Japan. [8] In the second half of 2010, the Chinese Ministry of Commerce cut export quotas with 72 %[9] and with a further 11% in the first half of 2011. They justified the cuts for environmental reasons. In July 2011, the World Trade Organisation (WTO) "found that China's export duties were inconsistent with the commitments that China had agreed to in its Protocol of Accession".[10] The analysis showed discrepancies in the treatment of domestic vis-à-vis international companies. In a statement, the Chinese Ministry of Commerce stated that it would continue to improve their regulation of rare earth exports.[11] Some industry analysts are, however, sceptical to China's intentions to change their policy, mainly due to the strategic importance of rare earth.[12]

The estimations of **rare-earth materials** made by Kato et al (2011) indicate large deposits on the bottom of the Pacific. Simultaneously, the markets for rare earths have grown considerably (from US$200 million in 2003 to US$2 billion in 2010 (Ernst & Young, 2010)) and are expected to growth further. Despite the growing use however, a US$2 billion dollar market is relatively small and as technological and economic barriers are considerable which indicates that the threshold to reach cost-effectiveness is high. On the other hand, rare earth minerals are currently playing a key role in the development of new technologies such as batteries for hybrid cars and renewable power. The European Commission's Working Group on defining critical raw materials concluded that rare earth materials are by far the material with the highest supply shortage risk of 41 materials investigated (EC, 2010). The high concentration of productions and stock to China makes Europe highly susceptible to (politically motivated) cuts in supply. Any threshold in price must accommodate the risks for supply shortage and level of substitutability.

3.1.4 New discoveries of deposits

In a ground-breaking article in Nature Geoscience, a group of Japanese researches recently proclaimed that the deep-sea mud in the Pacific presumably contains large quantities of rare earth and yttrium (Kato et al, 2011). The developments of new technologies and further research will determine the future of excavation.

3.1.5 Financial risks

There are substantial financial risks involved in deep-sea mining. To embark on a full-fledged project, one technology provider estimated that an order of minimum €450 - 500 million would be needed. Conventional land-based mining companies are normally risk-averse to such investment which hampers that part of the value-chain. The Nautilus project Solwara 1 may turn out a "make-or-break" situation for future large scale investments. The potential of commercialising mining for nodules, polymetallic sulphides and rare earth materials depends on the type of deposits. Commercial ventures in general are on a nascent stage and to date, no deep-sea mining is operational.

3.1.6 Environmental risks and management

There are considerable environmental risks with deep-sea mining. Mining on the sea floor affects the benthic zone and creatures at the bottom of the sea. Recovery of earlier extraction trials has proven very slow. The magnitude and implications for other sea-living creatures and plants are

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[8] http://www.nytimes.com/2010/11/20/business/global/20rare.html

[9] http://www.bloomberg.com/news/2010-07-09/china-reduces-rare-earth-export-quota-by-72-in-second-half-lynas-says.html

[10] http://wto.org/english/tratop_e/dispu_e/cases_e/ds394_e.htm#bkmk394r

[11] http://english.mofcom.gov.cn/aarticle/counselorsreport/europereport/201107/20110707636529.html

[12] http://www.reuters.com/article/2011/07/11/us-trade-rawmaterials-china-idUSTRE76A2TE20110711

highly uncertain. For international waters, the ISA would be the most natural body to regulate and monitor the effects. It remains, however, to stake out the extent of their mandate. Currently, exploitation licences requires the collection of baseline environmental data and the setting up of monitoring and reporting schemes.

The current environmental management suggestions tabled by the ISA includes the use of spatial environmental reserves. During a workshop on how to manage the Clarion-Clipperton Zone, a group of researchers suggested to designate Areas of Particular Environmental Interest (APEI) and rely on ecosystem based conservation methods. The setting up of APEI for protecting the sea-bed in the Clarion-Clipperton Zone was endorsed by the ISA in their 7th session in January 2011 (ISA, 2011c).

3.1.7 Legal drivers

Jarowinsky (2009) argues that the legislative framework regarding exploitation on the high seas provided by the UNCLOS II, has supported the development and interest in deep-sea mining. ISA regulatory processes, however, remain cumbersome and require the developer to set of reserve areas for compensation of environmental damage caused by the excavation. The compensation has been called a “tax” by industry (Hayden, 2004) and could weight down the rate of return. Mining on EEZs of national states is therefore more likely to take-off earlier. Bilateral agreements between companies and primarily small island states in the Pacific have already been made which indicated the industry’s interest in this way forward.

There has been local opposition from indigenous peoples on the islands impacted by the mining. In 2008, representatives from five provinces of Papua New Guinea (PNG) signed a petition which was delivered to Nautilus Minerals CEO David Haydon. The petition called for a full-stop of any activity which harms the livelihoods, i.e. the sea which sustains coastal groups. The indigenous peoples also urged for restraint and action based on Prior Informed Consent, and referring to negative experiences with Nautilus Mineral’s parent company, Barrick Gold, in land-based mining on PNG (Shaffner, 2008).

3.2 Assessment of commercialisation potential

3.2.1 Manganese nodules

For nodules there have been several attempts to commercialise mining. In the late 1970s governments of France, Germany, US, and Japan for example, spent hundreds of million Euros on exploration and development and technological developments. First, the size of the deposits determines the potential. For manganese nodules the threshold has been set at an abundance which must exceed 10 kg per square metre and an average of 15 kg/m^2 over areas of several tenths of a km^2 (ISA, 2006a). Moreover, technological developments in ROVs and exploration have increased the commercialisation potentials of nodule mining. Due already failed attempts to commercialise nodule mining, the outlook is uncertain. Nevertheless, technological breakthroughs or investments could jump-start the sector.

3.2.2 Polymetallic sulphides and ferromanganese crust

The first commercial venture for polymetallic sulphides will begin in 2013 off the coast of Papua New Guinea (PNG). The so-called Solwara 1 project headed by Nautilus Minerals Inc. will start excavation of copper and gold in the EEZ of PNG on 1600 - 2000 meters depth. A German ship-yard, Harren and Partner, has entered a joint venture with Nautilus to provide an operational support vessel for the mining activities. Harren and Partner will design and build the vessel at a cost of €127 million and deliver in first half of 2013. The vessel will be owned by a joint venture “Vessel JV” in which Harren will own 50.1% and Nautilus 49.9% (Reuters, 2011). Moreover, a UK based company, Soil Machine Dynamics, is designing three ROVs for seafloor production tools: an auxiliary cutter, a bulk cutter, and a collecting machine. These are based mainly on existing technology used in the oil and gas industry. Finally, a US based subsidiary to French company Technip are designing a riser and lifting system which pumps the mineral slurry to the production support vessel (Ibid.). The total cost for excavation and transport of ore in the Solwara 1 project is estimated to almost €290 million (US$ 407 million), excluding the cost for the operational support vessel.

A more recent development (April 2012) is that Nautilus has signed a binding agreement with a Chinese mining company (Tongling Nonferrous Metals Group Co. Ltd) for the sale of the product extracted from the Solwara 1 deposit located in the Bismarck Sea, Papua New Guinea. The agreement provides for the purchase by Tongling of 1.1 million tonnes per annum (subject to +/- 20% variation) of Solwara 1 material for a period of three years on a take or pay basis, commencing upon the first delivery of product from Solwara 1, targeted in Q4 2013 in accordance with a notification mechanism and includes an option to agree an extension of the arrangement. [13]

The future of mining polymetallic sulphides will heavily depend on the outcomes of Solwara 1. Key uncertainties remains in technologies for large scale excavation. Moreover, only a few known deposits viable for commercial excavation are known (Maribus, 2010). Nevertheless, considering European expertise and experience in deep-sea mining, the commercialisation potentials for necessary technologies and infrastructure is high.

3.2.3 *Rare earths and Yttrium*

Recent discoveries by Japanese researchers on the abyssal plains of REY have opened up a pandoras box in deep-sea mining (Kato et al, 2011). First estimations of the findings shows large potential, however, significant uncertainties remains on what type of technologies are needed to start exploitation.

3.2.4 *Summary of commercialisation potentials*

Commercialisation of deep-sea mining relies on a number of key drivers and barriers. Price of raw materials, legislative frameworks, technology and environmental considerations are central. These will be elaborated upon in the next section.

According to the World Ocean Review 2010, the polymetallic sulphides show the most potential in terms of commercialization. The sulphides are of high ore content and the only currently planned excavation venture focuses these types of deposits. Global size of deposits in sulphides, however, is expected to be negligible when compared to worldwide supply. Nodules and crust, on the other hand, are expected to be far more abundant (Maribus, 2010). If technical issues such as separating the crust from the volcanic substrate and viable harvesting methods for nodules can be found, then the impact on world resources markets can be substantial.

3.3 Most likely future developments

Four scenarios or “micro-futures” can be discerned when attempting to envisage the most likely future of deep-sea mining.

1. “The Nothing Scenario” - The Solwara 1 project yields no substantial or commercially viable results. Deep-sea mining is abandoned as a prospect to supply raw materials markets.

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[13] See http://www.mining.com/2012/04/23/nautilus-minerals-signs-landmark-offtake-agreement-for-solwara-1/?utm_source=digest-en-supplier-120426&utm_medium=email&utm_campaign=digest

2. “The Squeeze out Scenario” – Deep-sea mining takes off and the market is dominated by Chinese, Japanese and US governments and companies, squeezing Europe out of the value-chain.
3. “The EU Supplier Scenario” – Deep-sea mining takes off and Europe retains its forefront position as a technology provider and develops and supplies the market with high-tech products.
4. “The EU in Control Scenario” – Deep-sea mining takes off and European companies, supported by European governments, leads the exploration and extraction of mineral resources.

Given the inability to process ore off-shore and the expenses of sea transport, it is likely that EEZs will be exploited before international waters. The time-frame is fairly short and one interviewee estimated that within 18 months to two years, a full operation could be launched (Denegre, 2011). The industry is mainly waiting for large investments (with associated risks) to begin, and then the technological development should go quick (Van Muijen and van Bloois, 2011).

The question at this point is not if, but when deep-sea mining will start (Van Muijen and van Bloois, 2011).

3.3.1 The Nothing Scenario

The Solwara 1 project turns out to be a large disappointment. When excavation finally started, the technological problems with mining at great depths became imminent. Broken cutters and risers needed to be buried on the bottom of the coast off Papua New Guinea and investors saw their money disappearing into the great blue. Some debts were paid when the selling of the transportation vessel went through. Due to the Solwara 1 debacle, large financiers shy away from the investments needed to launch another attempt. Like in the early eighties, deep-sea mining remains a dream of a few and is not likely to be revived over the next decade.

Conditions for this scenario to be fulfilled

- Solwara 1 fails to deliver
- Prices on raw materials decreases
- Technology is not ready for deep-sea mining
- Environmental

3.3.2 The Squeeze out Scenario

The race for the under-water resources went quick and the EU was late on the bandwagon. China and Japan were early on approaching the ISA to acquire exploitation rights. Large non-European mining companies created alliances with south pacific states such as Nauru and Papua New Guinea which further alienated the Europeans, both companies and governments, at an early stage in the process.

In the first years of exploitation, European ship-builders and technology providers were essential for excavation to take place. Soon, however, South Korean ship-yards and American marine technology developers were able to mimic and improve the European ways of building ROVs, AUVs, and dredging equipment.

European governments were “late on the ball” and did not pull the diplomatic strings hard enough to have the ISA work in its favour. By acting more on individual basis than as the EU, European countries were unable to create the leverage for acquiring exploitation rights in areas with proven deposits. Moreover, funding for innovation remained domestic and scattered which enabled non-

European countries able to support their industry until it outmanoeuvred the European technology providers.

Europe is thereby forced to watch the deep-sea mining take off from the sidelines. The Europeans are benefitting from more raw materials on the market but are unable to reap the large benefits in terms of controlling the supply chain and develop technologies for excavations.

Conditions for this scenario to be fulfilled

- Deep-sea mining becomes a profitable exercise
- EU is unable to act as one at an international level
- European governments are not able to apply for explotation right in time
- European companies are not able to form alliances with pacific island states to exploit their resources
- EU is not providing the support necessary to pool resources scattered across Europe

3.3.3 The EU supplier scenario

It has been a long haul: with the help of entrepreneurialism, long trial and error with excavation and extraction techniques, and after quite some failures, 10% of the globe's precious minerals including cobalt, copper, zinc as well as rare earth come in the year 2030 from the ocean floors. Early attempts to mine manganese modules from cobalt crusts date back to the 1970s, when the governments of France, Germany, the US, and Japan already spent hundreds of millions on exploration and development. The size of the deposits has been a lure since decades. But technologies were not ready, and prices of minerals plummeted – at the time that the international legal framework (UNCLOS) had been put in place. In 2030, manganese nodules and cobalt crusts would still not be commercially exploited at a large-scale, due to both technological, commercial and environmental constraints. [14]

The first road to success would be the one to polymetallic sulphides: deposits which are the result of hot fluids being discharged through fractures (vents) between tectonic plates. [15]. It would take until 2014 until the first commercial venture for those polymetallic sulphides ('Solwara 1') would succeed in commercial excavating of copper and gold from the Exclusive Economic Zones of Papa New Guinea, by the Canadian mining company Nautilus Minerals Inc. The mining company had thereto designed and built a dedicated ship from the German Harren & Partners company. It had used state-of-the art extraction tools, such as ROVs, cutters and risers developed for deepsea oil winning – supplied by European partners. This success coincided with the start of the exploration of the largest known sulphide concentration, namely in the Red Sea, [16] The Saudi company Manafa had been given exclusive exploitation rights and early estimations valuating the deposits to $ 3.11 billion to $ 5.29 billion (copper, zinc, silver and gold) proved conservative.

A subsequent surge in marine mining started – licenses for mining in Exclusive Economic Zones were issued at high speed by governments across the globe, many of which in developing countries. Dominant mining companies, most of which from the US, Australia, and Canada, secured these licenses. Against initial expectations, international waters would not be commercially explored, as UNCLOS was restricting the number of licenses and imposing environmental charges. Furthermore, transport of thousands of tonnes of ore and deposits to processing plants over the

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[14] World Ocean Outlook, Chapter 7 "Marine minerals and energy", p. 151.

[15] Halfar, J. and Fuijta, Rodney M. (2002) "Precautionary management of deep-sea mining", Marine Policy, v.26, 2, p.103-106

[16] Bertram et al. (2011) "Metallferous Sediments in the Atlantis II Deep – Assessing the Geological and Economic Resource Potential and Legal Constraints. Kiel Working Paper No. 1688, March.

international waters proved very high [17](Hayden (2004), for example, argues that price for shipping will be a key condition for where mining activities will first take place.

A second road to success would be the excavation of rare earth. In 2010, when the shortage of critical raw materials emerged for the first time on the political agenda, large potentials of rare earths and yttrium were found in sea-floor sediments (mud). At depths down to 50 meters below the seafloor, a Japanese research team had estimated that the sea-floor contained more than all the rare earths buried on land (Kato et al, 2011). In certain hotspots, one square kilometre was estimated to contain 25,000 tonnes of rare earths (Jones, 2011) – much of it was found particularly large deposits around Hawaii. It would take however several years to exploit rare earths commercially.

Despite the well-known disadvantages and limits of land-mining, European mining companies were slow in shifting to the oceans. An initial attempt by the UK-based Neptune Minerals plc came to an end already in 2009, in the middle of the economic and financial crisis, to save capital. [18], and not able to present the necessary credentials to countries in control of the most interesting mineral-rich parts of the ocean. Nevertheless, European companies were able to take advantage of the surge in marine mineral mining as they were world leaders in adjacent technologies such as dredging, drilling, cutting, transport and ROVs, which will be essential in case large scale mining takes off. After an initial boom in construction of dedicated vessels, shipbuilding production then shifted to Korea, while conversion of traditional dredgers and bulk carriers took place in locations close to the mining grounds. Over time, marine mineral mining became a mainstream activity and slowly but surely European players were losing out.

Conditions for this scenario to be fulfilled

- Price development (as well as fluctuations) of minerals on the world market
- Successful execution of pilots, notably the Nautilus project at the New Papa Guinea coast,
- Metal content found in future exploration of ocean floor
- Subsequent access to private capital for investment and upscaling
- Technological advancement, mostly in the area of excavation devices, cutters and risers
- Environmental impacts remain under control (and cooperation with environmental NGOs)
- Acceptance of local coastal populations exposed to mining activities

3.4 Impacts, synergies and tensions

Table 3 Impact matric for medium to long-term developments

Function affected	Sub-function Affected	General	Baltic	North Sea	Mediterr.	Black Sea	Atlantic	Arctic	Outer most
1. Maritime transport and shipbuilding	1.1 Deepsea shipping	+	0	0	0	0	0	+	++
2. Energy and raw materials	3.1 Oil, gas and methane hydrates	+	0	0	0	0	0	+	+
5. Coastal	5.3 Protection of	-	0	0	0	0	0	-	-

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[17] Hayden (2004) "Exploration for a Pre-feasibility of mining Polymetallic Sulphides – a commercial case study.

[18] Mining Journal "Return to the Deep" , 4/3/2011

Function affected	Sub-function Affected	General	Bal-tic	North Sea	Medi-terr.	Black Sea	Atlan-tic	Arc-tic	Outer most
protection	habitats								

Explanation:

++ = Strong positive impact on other subfunctions/sea basins expected

+ = Considerable positive impact on other subfunctions expected

0 = Negligible impact on other subfunctions/sea basins expected

- = Considerable negative impact on other subfunctions expected

-- = Strong negative impact on other subfunctions expected

4 Role of policy

The extraction of marine mineral resources may require several areas in which public policy can make a difference.

1. *Need for political support to develop marine mineral resources;* despite the political concerns about a looming shortage of critical raw materials in Europe, there has not yet been a wide EU-concerted action to develop marine mineral resources as a strategic activity. Despite its 'key enabling' nature, and despite important political support provided to these activities in Japan and China, there appears to be a political vacuum yet.

2. *New financial instruments:* the subfunction is currently in a development phase and requires substantial investment, which is difficult to be generated by the sector itself – other than through mining companies. European suppliers are not in a position to invest by themselves the amounts needed for this type of activity. As regular banks are not inclined to take such risks, new financial instruments may need to be pursued. A 'European marine investment fund', partially funded by the EIB and with private equity and guarantees from Member States could be envisioned. It is important that new financial instruments take account of the longer term nature of such investments, as well as uncertain revenues related to fluctuations in commodity prices.

3. *Research & development:* many efforts still need to be put in production technologies and for shipping expeditions. Overall, the knowledge of the deepsea resources is still hardly explored and dedicated research efforts in this domain could bring substantial benefits to Europe. Clearly, much research is also needed in the better understanding and reduction of environmental impacts of this activity.

4. *Brokerage and match-making;* European players have much potential in this domain; however there is still a large degree of fragmentation. Existing initiatives, such as the Waterborne Technology platform, are aware of the potential but not necessarily driving yet. The Sustainable Mineral Resources Platform is not picking this activity up to date, and room exists therefore for additional

5. *Monitoring and support of the international legislative framework;* crucial for the future potential of this activity will be the international legislative framework – UNCLOS – and the extent to which is supports/conditions marine resource mining in a sustainable manner. EU Member States are directly represented in the UN institutions, but there would be scope for coordination of EU positions.

Annex 1: Interviewee list

Interviewee	Organisation	City/country
Prof. Dr. Uwe Jenisch	Christian Albrecht University	Kiel/Germany
Michael Jarowinsky	MC Marketing Consulting	Kiel/Germany
Henk van Muijen	IHC Merwede	Sliedrecht/Netherlands
Julien Denegre	Technip	Paris/France
Jorg Mutschler	VDMA	Hamburg/Germany
Paul Tyler	National Oceanographic Centre	Southampton/UK

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P.O. Box 4175
3006 AD Rotterdam
The Netherlands

Watermanweg 44
3067 GG Rotterdam
The Netherlands

T +31 (0)10 453 88 00
F +31 (0)10 453 07 68
E netherlands@ecorys.com

W www.ecorys.nl

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