

Our way towards the responsible exploitation of high-tech metals

Facts and challenges of Deep-Sea Mining



Why Deep-Sea Mining?

1	Increasing demand for seabed metals	Page 4
2	Deep-Sea Mining – a new solution for a safe and secure supply of metals	Page 6
3	Key Deep-Sea Mining technologies and services	Page 12
4	DSMA – international partners and projects	Page 14
5	Setting the highest international standards for responsibility and environmental protection	Page 16
6	Main goals of the DSMA The way ahead	Page 19 Page 20

As the world transfers to a low carbon future, Deep-Sea Mining is emerging as a challenging technology. This budding new industry is opening up windows of opportunity with regard to:

- The supply of critical raw materials for clean technologies and responsible industries
- The development and export of innovative Deep-Sea Mining technologies for world markets
- The definition of high technical and environmental standards to minimise impact

1 Increasing demand for seabed metals

Main branches, technologies and products and their dependence on seabed metals

Automobile design	Nickel
Electro engines	Copper
Rechargeable batteries/e-mobility	Cobalt, lithium, nickel, manganese
Magnets	Cobalt, nickel, manganese, copper, REEs
Fuel cells	Platinum, nickel
Catalysts	Platinum
Fibre optic cables	Germanium
Wind turbines	Copper, nickel, REEs
Photovoltaic, solar panels, superconductors, monitor screens, displays	Indium, germanium, trace metals, silver, cobalt, nickel
Laptops, cellphones	Cobalt, gold, indium, REEs
Radio Frequency Identification (RFID)	Silver, copper
Digitalization & industrial 3D printing	Cobalt, nickel
Aircraft & space & military, turbine engines, lightweight construction, airframes and components	Molybdenum, scandium
Medical instruments, implants	Cobalt-based alloys, titanium, platinum, indium

In today's high-tech world, it is essential for industrialised nations to have secure access to raw materials. As well as ensuring the ability of their main industries to innovate and compete, raw materials play a crucial role in honing and producing eco technologies and developing global projects such as green energy, e-mobility and digitalisation. Within the scope of these projects, metals are by far the most important raw materials, and demand is set to rise significantly, thus leading to higher prices.

With the soaring global demand for these raw materials outstripping the quality and quantity of deposits on land, there is a global rush to exploit new sources in order to secure long-term supplies. As land resources are increasingly depleted, the seabed is fast emerging as the most promising source of ores and minerals. Commercial Deep-Sea Mining is the key to unlocking these untapped resources and securing long-term supplies of high-tech metals from safe, verified seabed deposits. An additional advantage is that deposits can be mined from geopolitically stable countries.

Germany's industry currently consumes 8-9% of the world's overall metal production; the EU accounts for 30%, while China consumes 35-40%. In 2016, Germany imported metals worth around €46bn*.

A significant proportion of these high-tech metals are considered by the EU to be critical raw materials.

The European Commission published the 2017 List of Critical Raw Materials for the EU**, which contains the following core statements:

- "Given the continued strategic importance of raw materials for the EU manufacturing industry, the Commission is implementing a wide range of actions under the EU Raw Materials Initiative to help ensure their secure, sustainable and affordable supply. The list of critical raw materials for the EU is a central element."
- "The 27 raw materials listed are critical for the EU because risks of supply shortage and their impacts on the economy are higher than those of most of the other raw materials."
- "However, China is the most influential country in terms of global supply of critical raw materials, such as REEs, magnesium, tungsten, antimony, gallium and germanium."

The 27 raw materials listed include the following seabed metals:

- Cobalt: The Democratic Republic of Congo is the producer with a world market share of 64% (average 2010-2014)
- Germanium: China is the main producer with a world market share of 67% (average 2010-2014)
- Indium: China is the main producer with a world market share of 57% (average 2010-2014)
- Platinum group metals: South Africa is the main producer with a world market share of 57% (average 2010-2014)
- Heavy and light rare-earth elements (REEs): China is the main producer with a world market share of 95% each (average 2010-2014).

Development of prices for seabed metals

As always, market forces and financial aspects are decisive factors. The fixed-cost component is highly dependent on metal prices, metal grades, production rates, fees and royalties, taxes and insurance rates and "benefit sharing". Surging prices for critical raw materials in combination with new and evolved technologies represent the tipping point in favour of Deep-Sea Mining.

It is difficult to forecast markets and prices for metal commodities as these depend largely on economic growth and industrial development around the globe. The past years have seen a period of growth in the US, Europe (including Russia), in Asia as a whole and even in parts of Africa. This pattern may continue; the main drivers will

be China and the advanced developing nations, as these countries become increasingly industrialised and evolve into modern societies. Another global driver is climate change, which is forcing change in the electronics sector and in automotive technologies, with a strong focus on less polluting modes of transport.

The immense scale of the global automobile market, which currently exceeds 60 million vehicles annually, will generate a huge demand for nickel, cobalt, manganese and other minerals when e-mobility takes over and hybrid or all-electric cars are equipped with electric engines and rechargeable batteries. OPEC estimates that there will be roughly 140 million electric cars by 2040. In addition to the demand that can currently be projected, there is also the prospect of new key technologies requiring minerals and elements that presently are of little or no importance.

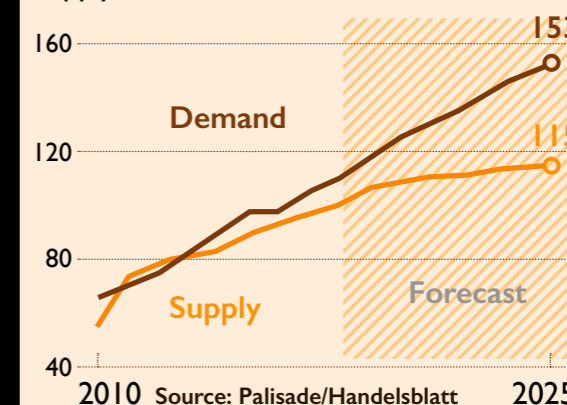
It is clear that shifts in demand, technology and major stakeholders will have a critical impact on market conditions, in most cases leading to shortages and rising prices, most likely for cobalt and rare-earth elements (REEs). In light of the fact that around 90% of all REEs come from China and 60% of cobalt comes from the Democratic Republic of Congo, a country that has a reputation for instability, the destruction of rain forests, persistent human rights violations, war lords and child labour, the "criticality" of supplies – and ethical reservations – are a rising problem. The new EU regulation (2017/821) addresses these issues by imposing due diligence obligations for imports from conflict zones and high-risk regions.

Examples of products in need of critical high-tech metals

1,000,000 car batteries (Toyota Prius)	10,000 tons lanthan plus lithium, cobalt, nickel, manganese
1,000,000 car batteries (BMW i3)	12,000 tons cobalt + 6,000 tons lithium
10,000 offshore wind turbines	10,000 tons copper plus 5,000 tons nickel
1,000,000 cellphones	6.3 tons cobalt, 0.3 tons silver, 0.05 tons neodymium, 0.03 tons gold

Dangerous shortfall

Cobalt (essential for batteries): Supply and demand in kilotons



* Raw Materials Report for Germany 2016, BGR (23.11.2017)
 ** Communication from the Commission to the European Parliament, the Council, the European and Social Committee and the Committee of the Regions on the 2017 List of Critical Raw Materials for the EU (13.09.2017)

Historical cobalt prices per ton (2010 –2018)



2 Deep-Sea Mining – a new solution for a safe and secure supply of metals

The background photo shows manganese nodules on the seabed

German exploration licence areas (marked in red) for polymetallic nodules in the Clarion-Clipperton Zone (CCZ), Pacific Ocean

German exploration licence areas for polymetallic sulfides in the Indian Ocean

ISA licences for

- Sulfides
- Nodules
- Crusts

With the demand for resources rising, the focus has shifted to the oceans, which cover 71% of the earth's surface. Already, oil and gas from offshore sources and electricity from marine wind farms help to meet the growing demand for energy. But there is more to be found here: the seabed is a rich source of metals and rare-earth elements (REEs). The earth's mantle contains **mineral resources on land and on the seabed**. These rich deposits contain many key minerals, including copper, cobalt, zinc, nickel, manganese, gold and silver, as well as REEs. The EU, Germany and many other countries have integrated deep-sea mining exploration and environmental monitoring activities in their respective R&D programmes.

The Federation of German Industries (BDI):
"There will be no high-tech 'Made in Germany' industries without a safe supply chain of critical raw materials."

Germany holds two exploration licences; one since 2006 for manganese nodules (75,000 km²) in the Pacific Ocean at the eastern end of the CCZ, and the other since 2015 for sulfides (10,000 km²) in the Indian Ocean. All contractors' rights and responsibilities for the German licence are vested in the Federal Institute for Geosciences and Natural Resources (BGR), a subordinate body of the Federal Ministry for Economic Affairs and Energy. About €50m have already been invested in mineral exploration and environmental monitoring activities.

The interests of the industry are largely represented by the DeepSea Mining Alliance (DSMA) in Hamburg, a group of 30 partners, which was founded in 2014.

The DSMA members include seven foreign enterprises and universities from Belgium, Denmark, France, Norway, Poland, Singapore and the Netherlands, which partly hold exploration licences for manganese nodules and massive sulfides.

International Seabed Authority – the governing body

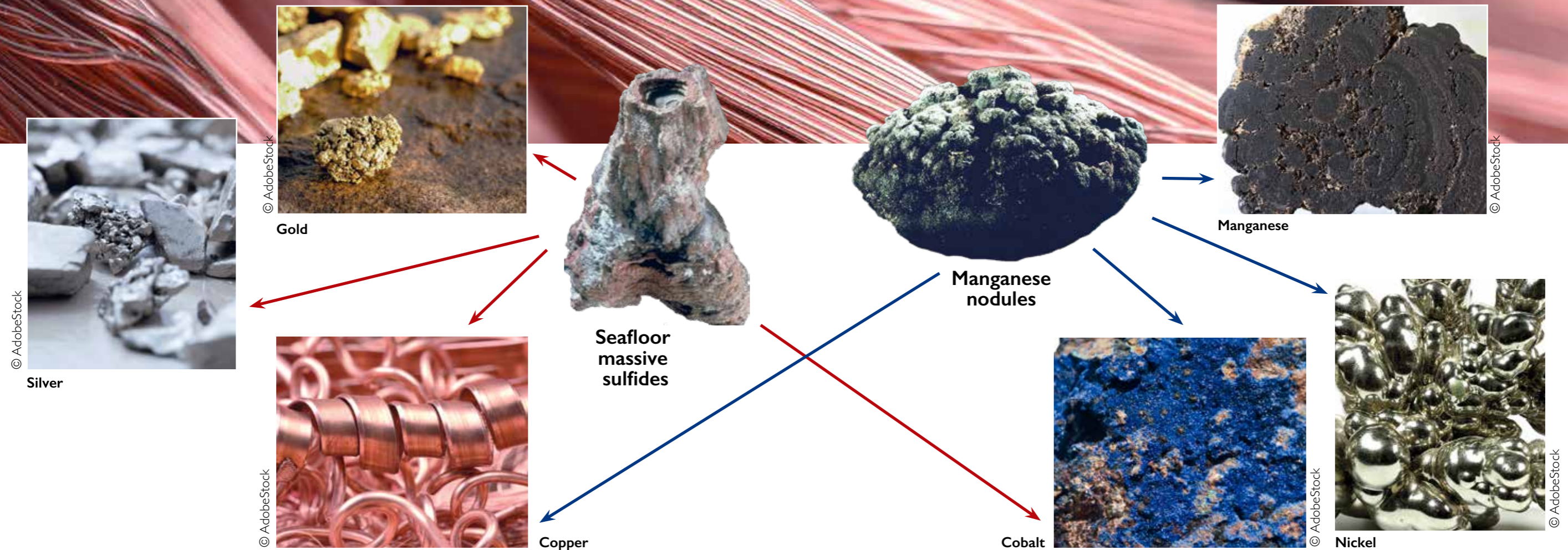
The International Seabed Authority (ISA) is responsible for the **exploration and exploitation** of mineral resources of the seabed in the Area, i.e. beyond the limits of the national jurisdiction of coastal states. Its legal basis is the United Nations' Convention on the Law of the Sea (UNCLOS) of 1982 and its corresponding Implementing Agreement (both in force since 1994).

The ISA, based in Kingston, Jamaica, is an autonomous intergovernmental organisation of the United Nations with 168 member states. Germany, like most industrial nations, has a permanent seat on the ISA committees. Its mandate includes the regulatory framework, environmental protection and control of activities. To date, the ISA has issued 29 permits in the form of contracts for deep-sea prospecting and exploration.

Deep-sea ore deposits

These 30 claims hold three different types of mineral deposits with rather high grades and quantities:

- **Manganese nodules**, i.e., potato-shaped polymetallic minerals present on the seabed at a depth of 4000m and below.
- **Seafloor massive sulfides (SMS)** with a polymetallic content found in the vicinity of hydrothermal vents ("black smokers") on mid-ocean and back-arc ridges at depths of around 1500 – 2500m.
- **Cobalt-rich ferromanganese crusts** present on the flanks and on top of seamounts, and containing cobalt, copper, manganese and REEs.



Currently, the interests of Germany, Belgium, France, Poland and Singapore are focused on manganese nodules and seafloor massive sulfides.

All types of deposits have high concentrations of the key metals, including cobalt, nickel, copper and manganese, required by a wide range of industries. Many seabed mineral resources, subject to local conditions, also contain different trace metals such as gold and silver and even REEs in meaningful qualities and grades as by-products. The exploration results are very promising, especially for seafloor massive sulfides. These by-products serve to enhance the profitability of future mining operations.

All three types are multi-metal resources, i.e. they contain a mix of different metals plus – in many cases – a “cocktail” of REEs. In other words: a single resource containing several minerals. The deposits of manganese nodules

are measured in kg/m² and relatively large areas of several hundred square kilometres are required. The sulfides and the crusts occur in high-grade local deposits of limited size.

Contractors are entitled to explore for minerals over a contract area for 15 years with the option of a five-year extension. Thereafter, the contractor can apply for the exclusive right to exploit the resources for a period of 30 years under the future Exploitation Regulations. As the first exploration contracts were awarded in 2001 and extended in 2016, the start of the exploitation phase is fast approaching. Accordingly, the new Exploitation Regulations are high on the ISA agenda, and the aim is to have

them come into effect after 2020 to provide legal security for investors and operators.

Deep-Sea Mining in international waters under the ISA regime is gaining momentum. Most of the 30 contractors operating under the ISA regime are poised to enter the testing phase for hardware development. Japan, Korea and China recently published positive test results for equipment, components and production systems. Germany, in cooperation with European partners, will file

applications with the ISA for collector and cutter testing to be performed in one or two of their contract areas. The first application was submitted in April 2018.

Full-scale mining operations can be expected to start after 2027. Cost estimates (CAPEX) for a mining unit plus processing plant on land range between US \$1.4bn and 1.6bn, depending on how many metals are to be extracted**. The cost is roughly the same as opening up a new mine on land.

Deep-Sea Mining in national waters

Mineral exploitation is also practiced inside waters under national jurisdiction (200 miles of Exclusive Economic Zones – EEZ) and on extended continental shelves. Companies digging for minerals here do not need to wait for ISA legislation because governments of coastal states can regulate mining under their jurisdiction. Here, exploration and in some cases exploitation licences are already a reality. Diamonds (Namibia) and phosphorites (Africa and New Zealand), placer (New Zealand) are traditionally mined in national waters. Metal mining is also planned by Saudi Arabia, Papua New Guinea (PNG), Japan and in other South Pacific island states within their huge 200-mile EEZ, which in some cases, like the Cook Islands, are larger than Europe. The Cook Islands' EEZ has promising deposits of manganese nodules with very interesting cobalt contents.

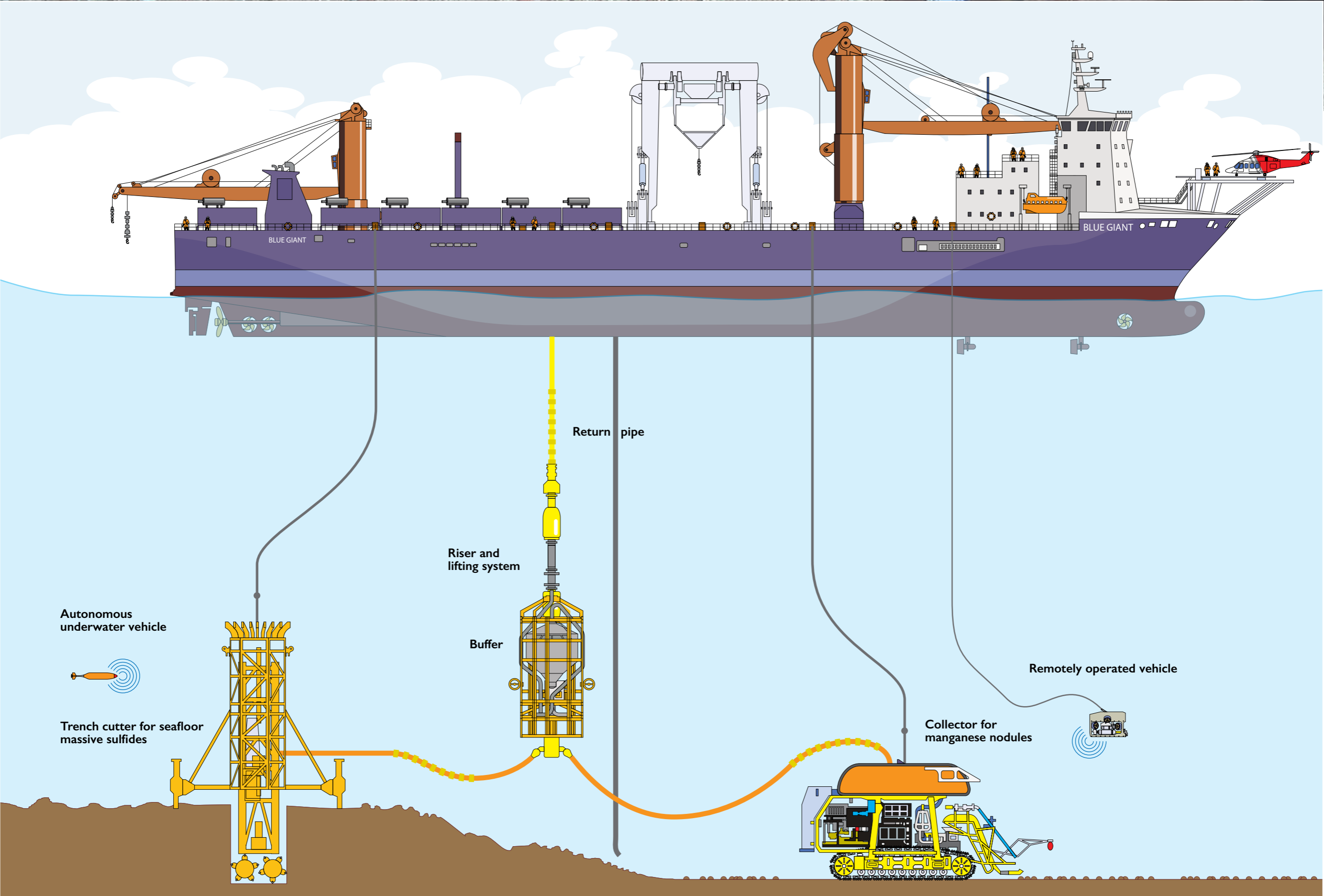
* Mark Hannington et al., 2010

** Analysis of the economic benefit of the development of commercial deep-sea mining in the areas in which Germany holds exploration licences from the ISA, as well as listing and rating of implementation options with emphasis on “Carrying out a pilot mining test”, Study on behalf of the Federal Ministry for Economic Affairs and Energy, December 2016

Metal content of manganese nodules and seafloor massive sulfides

Manganese nodules				Seafloor massive sulfides*			
Major elements	%	Trace elements	g/t	Major elements	%	Trace elements	g/t
Manganese	31.0	Titanium	2,600	Copper	up to 28.5	Cobalt	243
Nickel	1.4	Molybdenum	600	Zinc	up to 28.5	Silver	up to 118
Copper	1.2	Vanadium	490			Gold	up to 5.6
Cobalt	0.2	Lithium	130				

Complete commercial Deep-Sea Mining project



Graphic: Brian Sipple

3 Key Deep-Sea Mining technologies and services

In the next three to four years, the maritime and engineering industry will focus on solving the following key challenges:

- I. Responsible and innovative Deep-Sea Mining exploitation tools
- II. Development and connection of innovative technologies covering the entire Deep-Sea Mining value chain
- III. Preparation and realisation of cost-effective commercial Deep-Sea Mining projects.

Mining is reliant on economical, ecological and technological factors. One of the specific challenges of Deep-Sea Mining is that it requires the collaboration of a clustering variety of specialised branches:

- Seabed exploration
- Environmental monitoring, reporting, documentation
- Seabed exploitation equipment and technologies for seafloor massive sulfides (cutter)
- Seabed exploitation equipment and technologies for manganese nodules (collector)
- Underwater technologies (communication, energy supply, navigation & positioning, underwater robotics including remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs))
- Vertical transport system (buffer and riser)
- Exploitation vessel
- Ship's equipment including service and repair
- Transshipment at sea, transport to shore
- Zero-waste processing and refining technologies
- Raw materials trading
- Classification and certification
- All sectors of marine scientific research and services
- Insurance companies
- Finance and banks
- Legal sector: regulations, contracts, enforcement, dispute settlement



Exploitation vessel

© Harren & Partner



Collector for exploiting manganese nodules

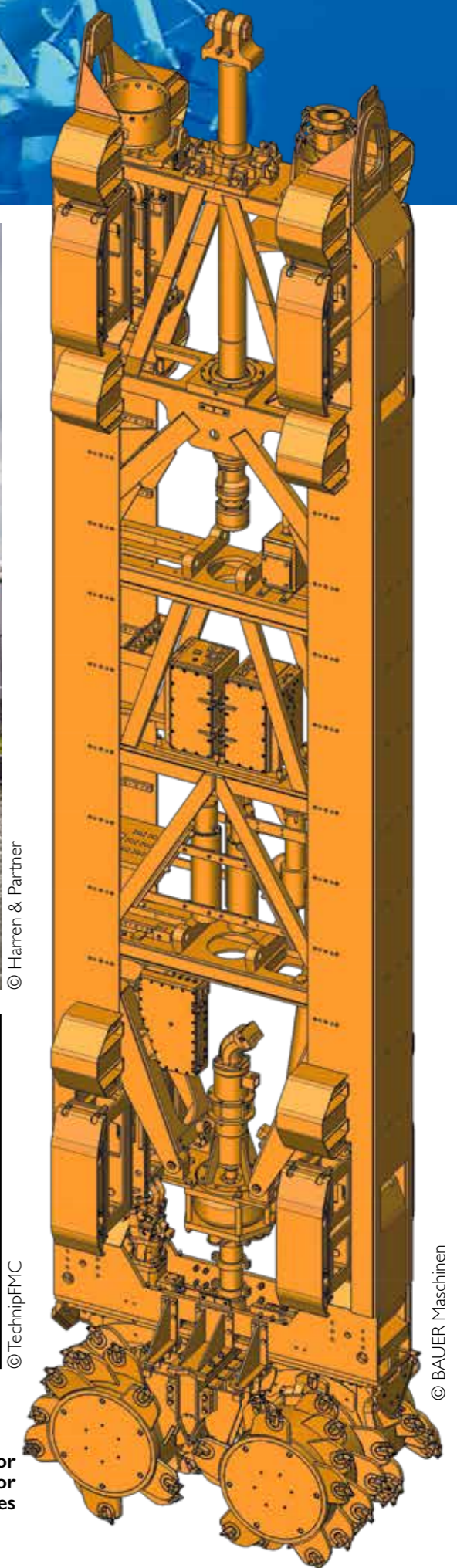
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Riser

© TechnipFMC

Trench cutter for exploiting seafloor massive sulfides



© BAUER Maschinen

4 DSMA – international partners and projects



Massive sulfides

DSMA and international partnerships

DSMA comprises almost 30 members, mainly from German industry. In addition, the alliance has members in France, Norway, Belgium, Poland, the Netherlands and Singapore. Members in France, Belgium, Poland and Singapore have their own ISA licences for manganese nodules and seafloor massive sulfides.

DSMA aims to further establish and expand international contacts and partnerships. This international approach has the advantage of reducing existing technological and scientific limitations in the value chain by cooperating with partners around the world.

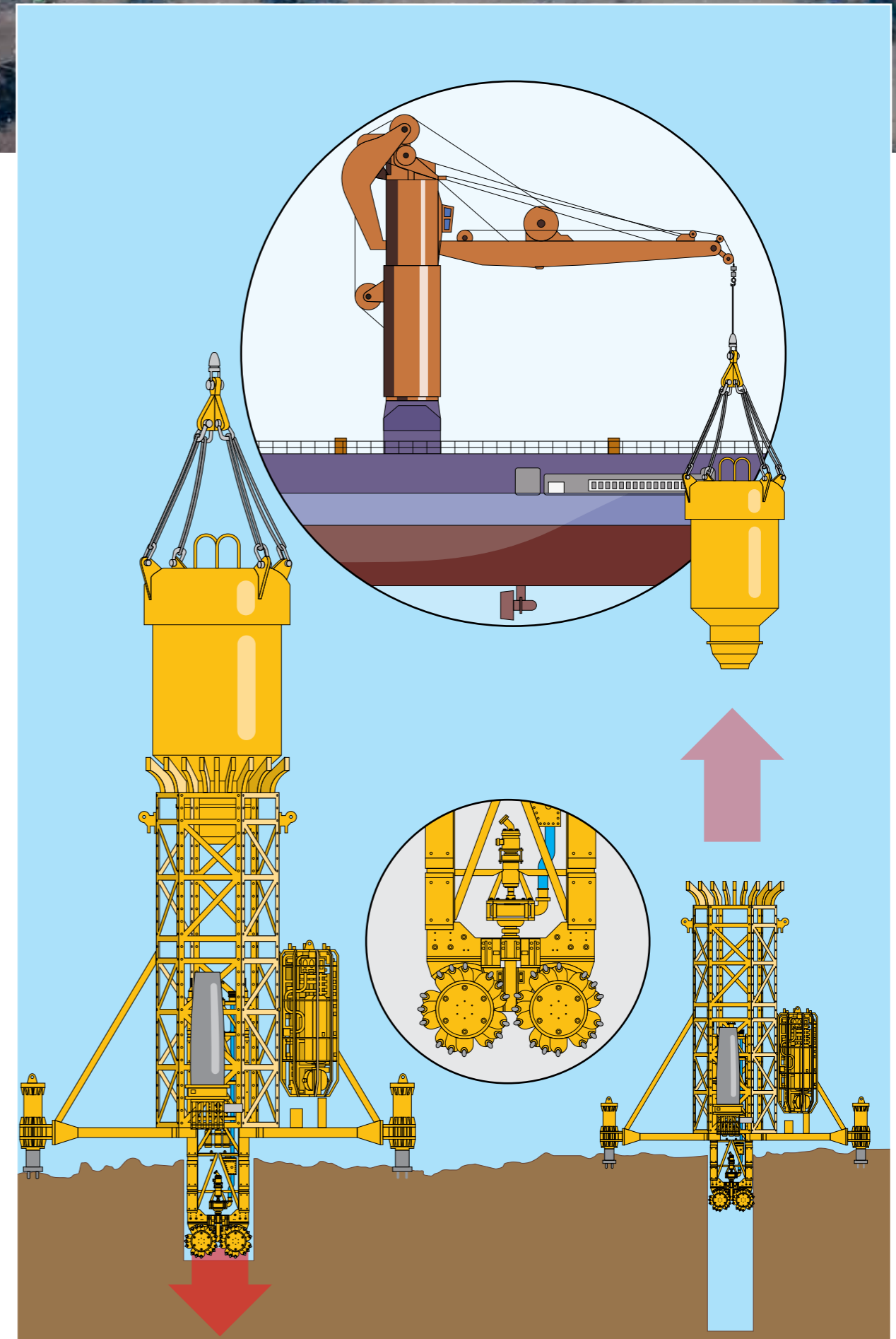
Main partner countries and projects

The international partners currently involved are mainly located in France, Belgium, Norway and Poland. DSMA is working with these partners to prepare and implement projects for manganese nodules and seafloor massive sulfides:

- Preparation and realisation of joint R&D and environmental monitoring projects
- Preparation and realisation of joint component tests
- Planned component tests in the next two to three years
- Preparation and realisation of full-scale pilot mining tests

Component test for sulfides – vertical approach (see facing page)

The trench cutter is suspended from a tripod frame. The cutter digs up to seven meters vertically into the seabed massive sulfides. This vertical approach was developed by DSMA member BAUER Maschinen GmbH, an expert in drilling equipment for offshore foundations and subsea exploration, in cooperation with DSMA member Harren & Partner to minimise the impact on the seabed surface. The cutting wheels loosen and grind the ore, which is then pumped through a hose into a container. Once this container is full, it automatically detaches itself from the frame; the ship's crane lifts it up from the seabed and unloads the ore into the hold. The ship will be operated by DSMA member Harren & Partner; a globally-operating provider of heavy lift, offshore oil & gas and wind energy services. Autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs) observe, control and document the work underwater and on the seabed.



5 Setting the highest international standards for responsibility and environmental protection

Recycling and substitution as alternatives

Recycling, substitution and “urban mining” of critical materials are important; however, current economic and technical limits allow for a recycling rate of only 30-40%. Considering that the world's population will hit the 10-billion mark within a few decades, this is an important aspect. Fighting poverty and ensuring that the world's citizens enjoy an acceptable lifestyle with adequate nutrition and health services, housing and energy, education and consumer goods – not to forget cars and cellphones – can only be achieved with the aid of modern industries that can help the world transit to a low-carbon future based on e-mobility and batteries. Needless to say, this energy transition depends heavily on a vast, reliable supply of high-tech metals, as does the digitalisation of modern life (Industry 4.0 based on the Internet of Things). Recycling and substitution, although not universal remedies, deserve full support, as the separation and sorting of composite materials can help to improve processes to refine polymetallic raw materials such as those mined from the seabed.

Environmental protection is absolutely essential within Deep-Sea Mining operations. On land, traditional mining – often in open-cast pits – is highly destructive to the environment, causing permanent damage to landscapes, rivers and habitats. Similarly, Deep-Sea Mining is not an activity isolated from the distinctive, in some cases unique, flora and fauna of the deep-sea environment, which is characterised by high pressure, low temperature and darkness. Deep-sea ecosystems have very special biodiversity characteristics; they are pristine, highly diverse, inhabited by rare and unknown species, and are extremely slow to recover. All these factors require a permanent dialogue across all sectors of marine scientific research. Establishing comprehensive baseline studies, impact assessments and ensuring that all activities are constantly monitored is a permanent challenge.

It is important to implement our environmental principles and standards before others dominate the discussion.

All human activities have an impact on nature. But what degree is tolerable? We believe the borderline is “serious harm” (to be prohibited) and “harmful effects” (to be minimised). Moreover, legal instruments such as the “polluter pays” system, reference zones, marine protected areas (MPA) and a liability fund are essential core elements in the regulatory regime. A sound regime of environmental protection with efficient controls and scientific services will be part of the emerging Exploitation Regulations – and a prerequisite for transparency and public acceptance.

Unlike other human activities, we have the opportunity to define the standards and establish the mechanisms before Deep-Sea Mining starts on a larger scale. Our industries and service providers cover all aspects. While the “zero-waste philosophy” is a long-term goal, “green mining” with its minimising production methods remains a realistic challenge. A better environmental footprint than in land-based mining is necessary. DSMA is committed to the complete fulfilment of all requirements and tools including – but not limited to – the following:

Environmental tools and functions:

- Precautionary approach
- Baseline studies
- Best available technologies (BAT)
- Environmental management plans (EMP)
- Environmental impact assessment (EIA)
- Monitoring programmes and independent controls
- Financial guarantees, liability and insurance

DSMA is very active in cooperating and exchanging views with the ISA. At the end of 2017, DSMA and the Federation of German Industries (BDI) participated with a detailed stakeholder comment on the draft regulations for exploitation of mineral resources in the international waters regulated by the ISA.

The core demands of DSMA and BDI are:

- Binding international testing regulations
A testing phase is widely regarded as the entry ticket for Deep-Sea Mining. There is an urgent need for application process regulations for
(a) the testing of mining equipment, parts and components, and
(b) the procedure of a pre-pilot mining test (PPMT) and/or a full-scale pilot mining test (PMT).
- A role for leading international classification societies
Classification societies with their wealth of experience in multiple marine and offshore applications should play an important role in the regulatory procedures of exploitation regulations, including the definition of standards and quality control, and in monitoring and inspection activities for future commercial exploitation contracts. Three leading classification societies are members of DSMA: DNV GL, Lloyd's Register (LR) and the American Bureau of Shipping (ABS).

The alliance continues to maintain contacts with non-governmental organisations (NGOs) and regularly participates in NGO events such as conferences and workshops.



American Bureau of Shipping
Classification society, presently classifying the world's first seabed mining vessel



BAUER Maschinen GmbH
Drilling equipment for offshore foundations and subsea exploration, seabed drill rigs



Bosch Rexroth AG
Bosch Rexroth supports mechanical and plant engineering efforts around the world



Continental/Conti-Tech/Oil and Marine Eddebüttel + Schneider GmbH
Special flexible rubber riser systems for deep-sea mining



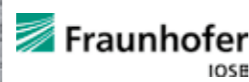
DNV GL SE
Classification and certification of shipping technology, maritime technology, manned and unmanned underwater vehicles



EmsteC
Design and development of hoses, oil transfer hoses, marine equipment and mechanical engineering for the Marine, Offshore and Construction industry



EvoLogics GmbH
Solutions for multiple underwater communication, positioning, navigation and monitoring applications



Fraunhofer-IOSB
Maritime systems, underwater robotics



Fraunhofer-Allianz AdvanCer
Competence bundling in the field of ceramic structural and functional materials



Geomar
The institute investigates the chemical, physical, biological and geological processes of the seafloor, oceans and ocean margins



GSR – Global Sea Mineral Resources NV
Global Sea Mineral Resources NV (GSR) is focused on the development of sustainable ocean mineral resources



Harren & Partner
Ship management in the sectors of heavy-lift, offshore oil & gas and wind energy



HYDROMOD Service GmbH
Management, consulting in deep-sea mining, oceanographic modelling, environmental monitoring



IHC Mining B.V.
Technology and project development, and construction for polymetallic nodules



Interoceanmetal Joint Organisation (IOM)
Regional geological and geophysical surveys in the Clarion-Clipperton Fracture Zone



J.D. Neuhaus GmbH & Co. KG
World's leading manufacturer of pneumatic and hydraulic hoists and crane systems



Keppel Offshore & Marine Technology Centre (KOMtech)
R&D and product development for offshore and deep-sea technologies



Lloyd's Register
Classification society



MacArtney Germany GmbH
Sales and service for oceanographic, geophysical and hydrographic equipment



MAERSK Supply Service
Marine solutions for safe, sustainable, and efficient offshore campaigns for exploration and exploitation phases



MC Marketing Consulting
Management and technology consulting for deep-sea mining



MHWirth
Drilling rig systems for the offshore oil & gas industry, several concept studies for deep-sea mining



Neptun Ship Design GmbH
CFD – Ship theory and ship hull optimisation, offshore construction units, merchant and passenger vessels



NTNU – Norwegian University of Science and Technology
NTNU has the main national responsibility for higher education in engineering and technology



Ramboll Germany
Civil engineering, offshore technology, engineering and installation, environmental engineering



RWTH, AKR, Aachen
Processing concepts and solutions for marine mineral resources



Sea & Sun Technology
High-tech underwater measurement technology for monitoring and assessing deep-sea areas



Siem Offshore Contractors GmbH
Service contractor for the offshore oil and gas/renewable energy industry



Technip FMC
Project management, engineering and construction for the energy industry

Main goals of DSMA

- Development of responsible, sustainable and innovative technologies for the entire Deep-Sea Mining value chain from a single source
- Comprehensive and on-going implementation of all national and international environmental requirements for future Deep-Sea Mining projects at the highest level
- Preparation and realisation of component tests leading to full-scale pilot mining tests
- Preparation and realisation of commercial Deep-Sea Mining projects at viable economic costs
- Promotion of Deep-Sea Mining as a global reference for sustainable and efficient technology
- Developing hardware (environmentally friendly collector, cutter, riser, zero-waste processing and refining technologies, monitoring systems and documentation)
- Contributing to setting the standards and shaping the regulatory framework (including financial responsibilities)
- Establishing commercial Deep-Sea Mining projects (2027-2028) managed by international (or European) consortia of operators and contractors
- Medium-term perspective: establish new industry-driven supply consortia and/or set up raw material supply entities
- Achieve a new quality in the close and regular cooperation between government, industry, science and other stakeholders
- Engage actively with the media and public through intensified public relations and media campaigns

Conclusion

- Deep-Sea Mining is in the pre-commercial phase, and new joint industry projects and components testing are imminent. Deep-Sea Mining will commence either under a stable ISA regime and/or in bilateral cooperation in the EEZ of coastal states.
- Commercial Deep-Sea Mining is an additional option – alongside land-based mining – for the dependable, long-term supply of metals and minerals from safe and certified seabed deposits. All industrial mega-trends, from energy transition to e-mobility and digitalisation, will profit.
- At the same time, a new industry is emerging. Many different branches and services can be actively involved, e.g. those representing clean technologies for mining, monitoring, processing and trading. Environmental protection in Deep-Sea Mining is essential, and it is a challenge that can be met by innovative engineering.
- Marine technology companies and all industries that depend on critical metals should integrate Deep-Sea Mining resources and technologies in their portfolios now to avoid missing out on new developments.

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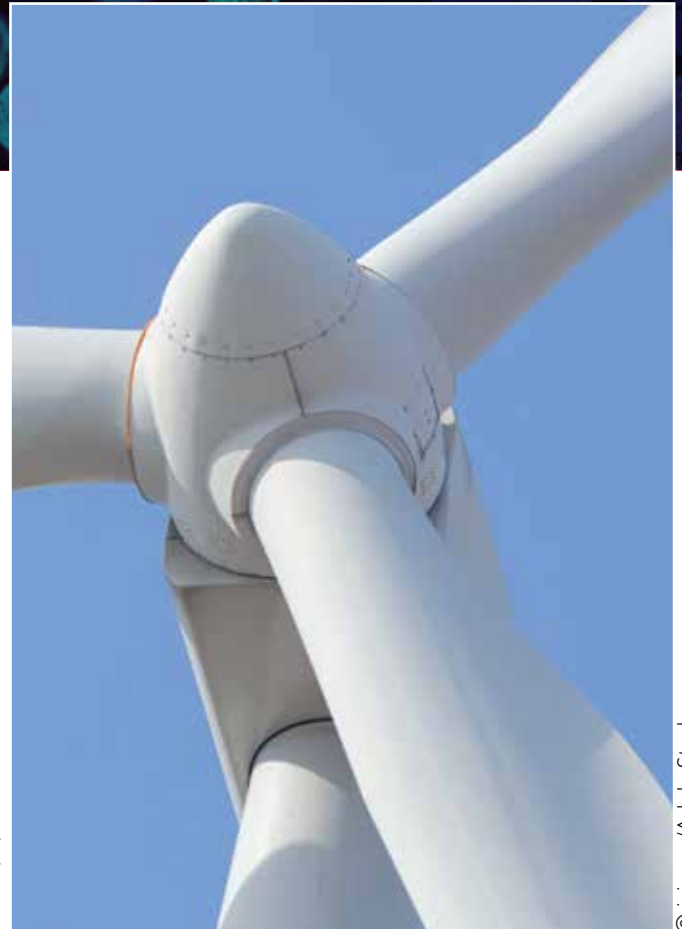
Production

Salzwassermedien



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The way ahead



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Main industrial applications with a growing demand for high-tech metals

The way ahead

DSMA is a strong source of expertise for the latest Deep-Sea Mining trends and developments.

We organise special Deep-Sea Mining workshops and events, and invite companies interested in this technology to benefit from our expertise.

We are committed to active networking and partnering for innovative technologies, testing and capacity building.



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