National Subsea Research Initiative

THE FOCAL POINT FOR SUBSEA RESEARCH AND DEVELOPMENT IN THE UK

UK Subsea Mining Capability Statement

April 2017

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1.5	**UK Subsea Mining Capability Statement**	**15.05.17**
Ver.	Reason for Issue	Issue Date

VERSION RECORD SHEET

Version	Issue Date	Section	Description of Update
1.0	14.02.17		Working draft issued for review / discussion.
1.1	07.03.17		Changes to document structure.
1.2	11.04.17		Comments incorporated.
1.3	20.04.17		PB comments incorporated.
1.4	15.05.17		Comments from meeting incorporated, reissued for review
1.5	06.07.17		Final

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1. FOREWORD

Subsea mining as an emerging industry is thought to be potentially worth between £20 – 60 Billion to the UK economy. It is considered to be about 10 years away from being a successful commercial industry.

It is critical for the UK to be involved in this industry as it emerges to capitalise on the exploitation subsea mining but also to ensure that the UK has the security of supply of critical minerals that it needs to support other industries.

At present the barriers to commercialisation of subsea mining are: technological, environmental, economic and regulatory. Scarcity of some minerals coupled with increasing usage is quickly driving the supply and demand curves to a price point where subsea mineral mining is becoming feasible. Equally, the greater abundance of the deposits available in the oceans as compared to land based deposits is driving progress towards opening up this industry. With depleting land resources the efficiency of conventional land based mining is lessening resulting in greater waste production and greater energy usage to achieve less.

Lack of experience with subsea mining means that to date no unifying standards exist for environmental impact assessments and seabed monitoring and thus it is difficult to attain consensus on what is acceptable. The lack of the legislative framework is presenting a barrier to the advancement in to the industry's commercialisation phase.

There is a renewed interest in subsea mining with new research activity underway with the aim of understanding better the environmental impact and reducing the uncertainty of evaluating finds and reducing the risk of operations.

Deep sea mining is likely to begin in 2018 with the Solwara project off Papua New Guinea. This project will be closely scrutinised not just for its technological pioneering advancements in mining engineering but also for how the environmental concerns are managed.

2. INTRODUCTION

The island setting of the United Kingdom has necessitated the development of technologies and methods to exploit the seas, from maritime engineering of cargo ships to putting divers on the seabed. The need to develop these industries has strengthened the UK's position as a centre of excellence in subsea and maritime engineering.

Subsea mining is an emerging industry which presents environmental, technical and legal challenges to those who look to exploit these resources. The purpose of this statement is to demonstrate the capabilities of the UK supply chain in subsea mining and showcase technical innovations and ongoing cutting edge research.

For the purpose of this statement, the mining supply chain was split into six themes:

Environmental Science	How the environmental challenges are being investigated with a view to developing subsea mining in a sustainable manner.
Mining Processing /Technologies	The mineral harvesting machines and associated equipment that a mining company would be looking to operate to extract value.
Prospecting & Geotechnics	How resources can be discovered and appraised.
Sea Monitoring	The methods of monitoring mining activities in order to assess their impact to the marine environment.
Vessels	The requirements of surface vessels for all stages of subsea mining from prospecting to mining activities.
Legal and Financial	The policies outlined by the International Seabed Authority (ISA) which companies must comply with in international waters and the financing of mining projects.

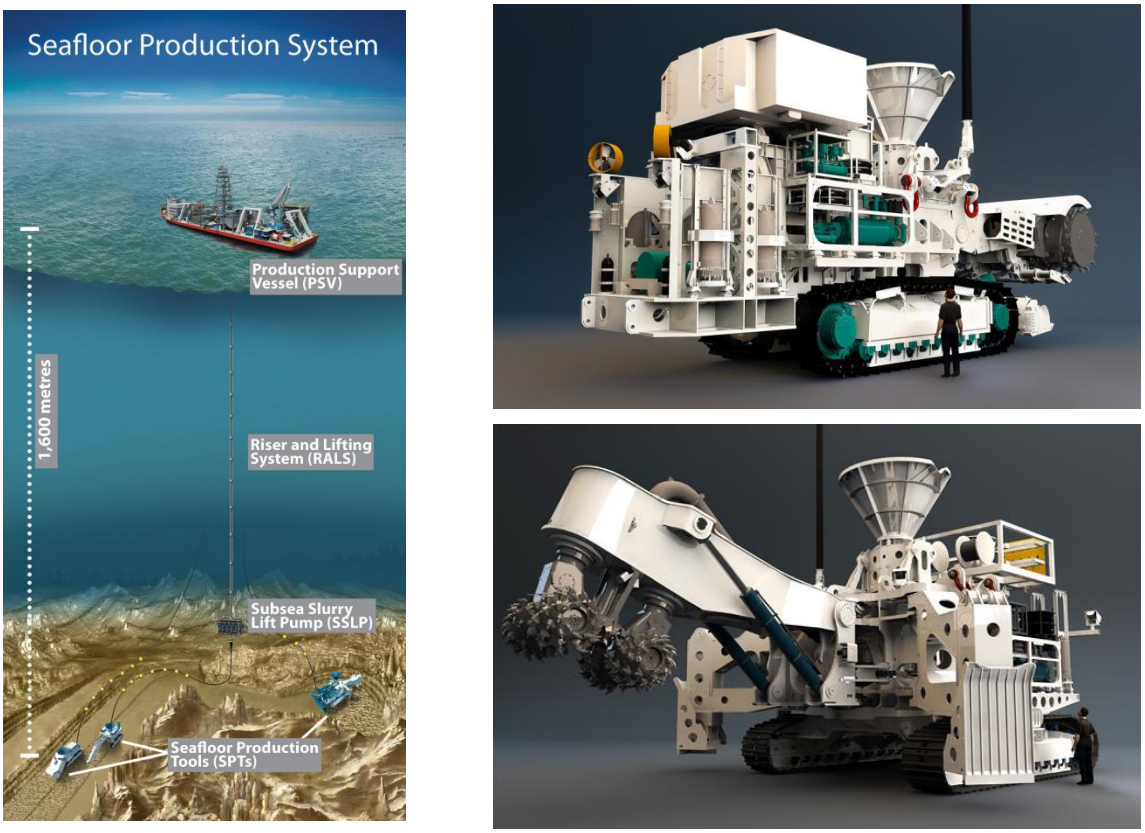
These themes were chosen as they represent major challenges to be overcome in the subsea mining industry. This statement shall outline the UK's expertise within these themes and highlight companies that already adding value to subsea mining projects. A brief overview of the challenge is outlined and thereafter excerpts from companies capability statements are provided, these describe the products and services UK companies already provide to the industrial sector. Of course, we already have a very strong capability supporting subsea in Energy, Defence and Ocean science. Subsea mining offers an opportunity for companies to diversify and support this emerging industry.

3. BACKGROUND

Subsea mining involves the recovery of minerals that occur in both shallow and deep ocean environments. This includes nearshore areas, continental shelf areas as well as deeper ocean seamounts, mid-ocean ridges, and ocean basins.

The most common mineral types that are exploited on the near shore environment are sand and gravel deposits that are a common source of construction materials.

Marine minerals that occur in the deeper parts of the ocean are referred to as deep sea minerals.



(Photos Courtesy of Nautilus Marine, Inc. and SMD Limited)

Figure 1 – Illustrative subsea production mining equipment

Extracting minerals from the sea is not a new activity, many countries extract sand and gravel for construction purposes and have been doing so for decades. Sand and gravel are extracted by ships which recover them from the ocean floor using a suction dredging method.

Minerals below a depth of 500m beneath the seafloor, are not amenable to extraction using extended dredging techniques. A subsea mining machine is required as opposed to a tool dragged by a vessel utilised in dredging. Figure 1 illustrates the techniques and equipment used for deep sea extraction.

Deep sea minerals may be deposited on the surface or subsurface of the deep seafloor by natural geological sedimentary, precipitation and volcanic processes. There are different types of potentially valuable deep sea mineral deposits that occur on the seafloor such as iron and manganese in nodular and encrustation forms, massive sulphides in rock or mud forms, phosphates and metallic sediments amongst others. The

three major deposits that can potentially be developed are: Seafloor Massive Sulphides (SMS), Manganese Nodules, and Cobalt-rich Crusts.

SMS deposits are formed by active hydrothermal vents that occur in mid-ocean ridges. A hydrothermal vent is a crack in the earth's surface from which superheated water is discharged. SMS deposits are typically found in water depths ranging from 0 – 5,000 metres.

Manganese nodules are found in abundance in the Clarion Clipperton Zone in the Pacific Ocean, at 4,000 – 6,000 metres water depth. Sizeable deposits have also been found in the Penrhyn Basin within the Cook Islands exclusive economic zone (EEZ), the Peru Basin, the southern tropical Indian Ocean as well as within Japans EEZ.

Cobalt-rich Crusts are found on the flanks and summits of seamounts, ridges and plateaux where currents have swept the ocean floor clear of sediment. These crusts can be found in water depths between 800-2400 metres. Again, high concentrations of these resources can be found in the Pacific.

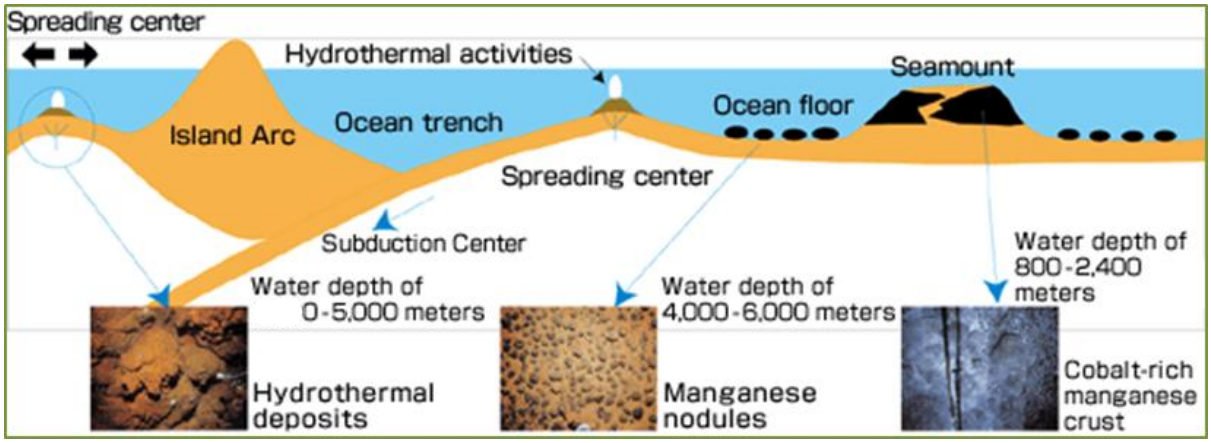


Figure 2 – Deep sea mineral deposits occurrence. *Source: JOGMEC (2014).*

In addition to deep sea minerals, there are large amounts of methane hydrates on and slightly beneath the sea floor. Some countries hope to become independent of energy imports by exploiting marine gas hydrate deposits near their coasts. The technology for economic production is not yet available. Moreover, the risks to climate stability and hazards to marine habitats associated with extraction of the methane hydrates must be evaluated.

Exploration for methane hydrate deposits in the seas has intensified over the past 10 years. Particular interest has been shown by countries like Japan and South Korea. They have almost no conventional fossil energy reserves of their own and therefore depend on the import of large quantities of gas, coal and oil. With methane hydrates from their own territorial waters they could significantly decrease their dependence on imports and their exposure to energy price fluctuations.

3.1 EARLY RESEARCH AND DEVELOPMENTAL PROJECTS

The UK subsea mining community has been involved in several projects to advance the development of commercial subsea mining and better understand the impacts of such an industry. These projects have included:

Blue Mining
http://www.bluemining.eu/
Blue Mining is an international European consortium of 19 industry and research organisations with various fields of expertise. The Blue Mining consortium will develop solutions that aim to bring sustainable deep sea mining closer to fruition. The project addresses aspects of the value chain such as resource discovery and evaluation to exploitation technologies as well as the legal and regulatory framework.

Blue Nodules
http://www.blue-nodules.eu/
Blue Nodules is a research and innovation project to develop a deep sea mining system for the harvesting of polymetallic nodules from the sea floor with minimum environmental impact. Specifically, this project concentrates on in-situ processing, material transport and onboard processing.

Managing Impacts of Deep Sea Resources Exploitation (MIDAS)
https://www.eu-midas.net/
Managing Impacts of Deep Sea Resources Exploitation (known as the MIDAS project) a multidisciplinary research programme investigating the environmental impacts of extracting mineral and energy resources from the deep sea. The areas explored by this project were; the physical destruction of the seabed as a result of mining, potential catastrophic slope failure from methane hydrate extraction, the effects of particle-laden plumes which might be released during the mining process and the effect of possible toxic chemicals released during mining on the deep-sea ecosystem. This project has now come to a conclusion and results can be found on the MIDAS website.

MarineE-tech
http://projects.noc.ac.uk/marine-e-tech/
MarineE-tech is a UK funded research programme led by the National Oceanography Centre, which is investigating the origin and formation of subsea Ferromanganese crusts, and studying the potential environmental impacts that could arise from the extraction of these minerals.

Viable Alternative Mine Operating System (VAMOS)
http://vamos-project.eu/
The Viable Alternative Mine Operating System (VAMOS) Project is part of the European Union Horizon 2020 programme. The aim of this project is to design and build a robotic underwater mining prototype with associated launch and recovery equipment, which will be used to perform field tests at four EU mine sites.

A research project that is about to emerge from the university of Delft will investigate the impact and mitigations of the disposal of subsea mining tailings (process waste). It is unknown if anyone in the UK is providing input into this proposed programme of work.

4. STATEMENT OF CAPABILITY

4.1 ENVIRONMENTAL SCIENCE

The environmental impacts of subsea mining are not fully understood. The activities involved in subsea mining could have detrimental impacts on localised populations as well as an impact on world oceans through the potential extinction of unique species which form the first rung of the food chain (DC Bureau). Before commercial seabed mining can take place, it is important to research; community ecology, species identification, distribution, genetics, resettlement patterns, etc. The International Seabed Authority regulates subsea mining activities in international waters and has developed guidelines for environmental impact assessments and environmental baseline studies.

The UK has lead the world in Renewable energy from the marine sources. There are key resources and capability that can drawn upon to enable the realisation of subsea mining. Specific examples include the comprehension of the marine environmental impacts brought about by industry, specialisation in this field is apparent in St Andrews University and Scottish Association of Marine Science (SAMS).

British Geological Survey (BGS)
In the area of marine environmental sustainability and impact assessment, BGS construct and deliver baseline and monitoring surveys including interpretation and final reporting for environmental impact statements. BGS geologists and hydrogeologists are capable of developing detailed 3D sub-surface models to assess resource potential.

BGS staff have also worked in advisory roles, helping to formulate strategic documents and acting as expert witnesses with regards to environmental issues surrounding development of seabed and subsurface resources.

BGS has worked with the Department of Environment and Conservation (DEC) and Mineral Resource Authority (MRA) of Papua New Guinea investigating impacts of Deep Sea Tailings Placement (DSTP) and methods of mitigation since 2006.

Marine Ecological Surveys Limited (MESL)
MESL's principal focus involves studying the marine environment and using multidisciplinary scientific techniques to map the seabed. By combining the results of such studies with their understanding of marine ecology and the marine environment to identify sensitive environmental resources, the extent to which such resources might be sensitive to anthropogenic impacts and the degree to which these resources are likely to recover following disturbance.

National Oceanography Centre (NOC)
The National Oceanography Centre (NOC) is the UK's leading institute for integrated ocean research and technology development from the coast to the deep ocean. The NOC undertakes environmental baseline studies, dealing with the cumulative impacts, risk and uncertainty and has a strong environmental research group including habitat mapping / monitoring with data acquisition, processing and interpretation to assess baseline conditions and the ecological impacts from seafloor mineral extractions. Key capabilities include repeat surveys (with AUV / ROV) and deployment of long term sensors and landers.
Through the MIDAS project, NOC assessed environmental impact using an Autonomous Underwater Vehicle (AUV). This exercise assessed seafloor, sediment and ecosystem characterisation over wide areas of the ocean.

Plymouth Marine Laboratory (PML)
PML Applications is the gateway to accessing the latest marine research and technology from the Plymouth Marine Laboratory for commercial use. In this way they can quickly apply state of the art best practice and peer reviewed methodologies to environmental assessments. Coupled to this, with their access to the latest physical and ecosystem modelling in one of the largest academic groups of its kind in the world, they can quickly develop the tools required to model complex environmental issues.

PML Applications Ltd. is able to offer the very latest robust methods to track natural environmental patterns, identify impacts and detect change in diverse marine assemblages. Many of the industry accepted methods and programmes used to analyse multivariate data were also developed at PML and can be used to their full potential by their technically skilled staff.

Plymouth University
Plymouth University's Deep Sea Conservation Research Unit have expertise in survey and identification of deep-sea animals using trawls, Remotely Operated Vehicles (ROVs) and AUVs. Additionally, they study deep-sea food web structure, population genetics, population connectivity and larval dispersal. Applied outputs include deep sea habitat mapping, species distribution modelling (predictive mapping) and habitat classification, design of deep sea and high seas marine protected area networks and spatial management. They are currently engaged in subsea mining relevant projects funded by the UK Government and UK Seabed Resources Ltd.

HR Wallingford
HR Wallingford assesses the environmental impacts of deep sea mining, ensuring that consenting decisions are based on robust evidence. They can assess sediment release and dispersion from mining sites, sediment re-suspension, and the propagation of underwater noise from extraction activities. HR Wallingford advise developers and regulators on the effects of near-shore extraction on coastal erosion and sediment movements. In special cases they conduct laboratory tests and field trials to provide additional reassurance that modelled findings are robust. Recent projects by HR Wallingford include undertaking underwater sound and sediment plume studies for proposals to extract phosphate from seabed sediments in Mexico and New Zealand.

Royal IHC
IHC perform plume dispersion predictions by using commercially available as well as in-house developed software and assesses the effects on local ecosystems. This has been developed from their experience with dredging operations in oil and gas.

Fugro
Fugro's UK operating companies have industry-leading experience of conducting deep sea environmental baseline and monitoring surveys to depths of over 4700 m around the globe. Fugro conducts multi-disciplinary deep water studies incorporating geophysical, geotechnical, physico-chemical sediment and benthic fauna sampling to map and characterise the seabed over large scales. Data and samples acquired are processed and analysed in Fugro's UK facilities. Fugro's UK marine biologists document and characterise deep sea communities as part of seep-hunting surveys, including the world's largest seep survey, eventually covering an area of approximately 800,000 km2.

Fugro participated in the MIDAS and VAMOS research projects, investigating the potential environmental effects of deep sea mining. Fugro provided expert commercial survey and impact assessment experience to the MIDAS consortium, informing academic research efforts, and also led the final research cruise. Fugro is integrating cutting edge environmental sensors to the VAMOS mining vehicle for verifiable environmental measurements of mining activities.

4.2 MINING / PROCESS TECHNOLOGIES

Deep sea mining technologies are in their infancy, present mining systems have incorporated a mining and extraction system, this then feeds into a vertical transport system, or riser, to the mining vessel. In principle, such an approach is very wasteful in that large quantities of low value material has to be transported over long distances. This is to enable the processing and extraction of the high value, low quantity product before the waste is transported back to where it originated. Presently, If the ore is processed offshore then the process water and tailings need to be transported back to the seabed via riser system. A significant technical challenge / opportunity exists to process the material subsea and only retrieve that which has value. Mining support vessels will be covered specifically later in this document - Section 5.

The mining and extraction machines are being conceived to operate in a manner similar to modern ROVs and would incorporate a control system, method of propulsion (possibly tank like tracks or Archimedes screws) and a method of collecting mining ore, either through mechanical means or hydraulically through water cutting and dredging. Further considerations for such a machine would be a tether management system (TMS) and a launch and recovery system (LARS) on the vessel. The UK has renowned expertise in this area, due to its experience in pioneering deep (beyond diver depth) oil and gas extraction.

Considerable technical opportunities arises in the processing / separation of materials. Different approaches may be necessary for the different minable products.

Risers
Considerable experience has been amassed in design and operation of risers in oil and gas field developments. For the subsea mining application the vertical transport system must incorporate robust materials as it will be expected to consistently transport suspended solids which could potentially erode the transport system. Another significant challenge is the water depth of mining sites meaning longer risers which are subjected to various hydrodynamic loads.

2H Offshore
2H Offshore played a key role in the development of the vertical transport system for the EU funded 'Blue Mining'. The riser that has to follow a seabed mining crawler presents design challenges not only in terms of water depth, but also a free hanging, un-tensioned state of the riser which exhibits higher motion response compared to risers that are fixed to the seabed. 2H have the extensive relevant experience of this type of system gained from installation engineering of deep water risers for oil and gas.

Royal IHC
IHC are part of the EU subsidised programmes, Blue Mining and Blue Nodules currently running and developing technology for manganese nodules mining in the Clarion Clipperton Zone. Blue Mining focuses on the development of the vertical transport system.

Underwater Mining Vehicles
The UK has a history of the design, manufacture, operation and procurement of underwater vehicles such as work class ROVs and trenchers. The proposed mining machines have a lot in common with these in terms of control systems and ancillary equipment such as launch and recovery systems.

Royal IHC

IHC are part of the EU subsidised programmes, Blue Mining and Blue Nodules currently running and developing technology for manganese nodules mining in the Clarion Clipperton Zone. Blue Nodules, focuses on the mining machine, umbilical, jumper hose, umbilical, vessel, and topside dewatering and transfer to a bulk carrier.

SMD
SMD's world-leading subsea vehicle design and manufacture status was recognised with the award of the contract to design and build the first deep-sea mining tools by Nautilus Minerals, with three vehicles designed to operate in depths of up to 2,500m on SMS deposits. The contract included three subsea mining machines with weights up to 310t, vessel-based power and control systems, pilot consoles, umbilical systems and Launch and Recovery Systems (LARS).

As mentioned previously the description provided above represents the companies already servicing the subsea mining industry, there is a wealth of subsea expertise who design, build and operate subsea machines all of whom could provide and contribute to this emergent sector.

Fugro
Fugro designs, builds and engineers ROV systems and subsea tooling in the UK for the Fugro fleet. Fugro also manufactures custom seafloor vehicles such as tracked ROV systems for cable laying or blow-out preventer intervention. These capabilities provide a strong research and development foundation for the marine mining tools and supporting technologies of the future.

Fugro is currently exploring ways to apply their knowledge of drill cuttings recovery and processing to seabed mining applications. Expertise in deep water drilling and rock/mineral recovery to surface (especially in environmentally sensitive areas with restrictions on turbidity) has resulted in several innovative solutions with potential for subsea mining.

4.3 PROSPECTING AND GEOTECHNICS

The vastness of the seabed makes prospecting challenging. An observation has been made that many of the hydrothermal vents that have been discovered to date are by coincidence during expeditions in volcanically active ocean regions. Scientists believe that there are many old SMS deposits which may not harbour the unique ecosystems found at active vents, these sites might be more viable for mining as they pose a lesser environmental impact. Prospecting for seabed "minable" resources is fairly immature, that is, there are not widespread searches underway to support an industry.

In order to prospect mining sites during surveys, several techniques can be employed such as side scan sonar, photographic surveys and high-resolution bathymetry. The EU funded Blue Mining project is also investigating the use of near bottom seismic reflection and refraction as well as towed electromagnetic techniques to prospect subsurface minerals.

Towed Systems & Autonomous Underwater Vehicles
Conducting a survey on a large area can be done using towed equipment or AUVs, these vary in size, but typically do not require more deck space than a work class ROV for launch and recovery.

AquaGeo
AquaGeo provides scientific portable solutions for comprehensive exploration and prospecting of ore and solid minerals. Portability is key for surveys of this complexity so that it can be deployed using limited resources. In addition, the equipment has to be effortlessly and safely deployable from any suitable marine platform.

Geological surveying can be conducted within the Economic Exclusion Zones (EEZ) to include sampling and on-board data analysis. The multi-beam echo sounder can carry out analysis of both internal and deep-water areas (up to 11km).

Prospecting includes environmental monitoring, and hydrophysical and hydrobiological investigations.

National Oceanography Centre (NOC)
NOC have been developing new seafloor observation techniques and strategies to identify and characterise ocean resources, especially: SMS deposits, cobalt crusts and manganese nodules. NOC hosts the largest research fleet of marine autonomous vehicles in Europe and have over 20 years experience of developing and deploying such vehicles in challenging and hazardous coastal and deep sea environments. The AUV developed by NOC can be deployed for three months at a time to collect data for seafloor mapping including seismic refraction data, electromagnetic data and visual survey. NOC also have capacity in deep-sea mineral exploration through on bottom instrumentation including Ocean Bottom Seismic and Electromagnetic Survey.

Physical Sampling
To obtain subsurface samples in potential mining sites, seafloor coring equipment can be utilized. This equipment can drill core samples to be examined back on shore for their physical properties, mineralogy and geochemistry.

British Geological Survey (BGS)
BGS have experience of working with industry to develop bespoke solutions to subsea problems, and provides a unique facility within the UK for sub-bottom robotic and autonomous coring. One example is the Rock Drill 2 (RD2); capable of coring gas hydrates, methane derived authogenic carbonates and SMS deposits. The latest RD2 has a capability to take cores and geophysical logs up in boreholes up to 55m sub-sea, in water depths of up to 4000 m.

BGS have significant skills that are relevant to deep sea mining, from specialist drilling, coring and logging technology capable of working in water depths of up to 4000m, to interpretation and analysis of subsurface seismic datasets, geochemical analyses of core material, 3D modelling of the subsurface, project management, and landscape / geohazard interpretation in both shallow and deep subsurface scenarios.

Plymouth University
The Plymouth Electron Microscopy Centre is a centre of excellence equipped with a suite of scanning electron microscopes suitable for determining mineralogical composition of raw materials. The centre is currently engaged in a project to determine and quantify the texture and mineralogy of polymetallic nodules, with a focus on rare earth element and platinum group element rich phases. The state of the art software allows for automated mineralogical scanning for minerals or elements of interest.

Royal IHC
IHC company, TI Geosciences (Joint venture between IHC & Tompkins) provides deepwater geotechnical site investigation services with a range of equipment including deep push cone penetration test (CPT) and remote seabed drilling systems.

TI Geosciences provides CPT and gravity coring services based on its deep push, buoyancy stabilised, deep water CPT. Remote seabed drilling services are also provided with the sonic wireline operated remote drill remote seabed drilling systems.

TI Geosciences has been involved in the coring of gas hydrates in Sea of Japan for Meji University (Japan), in collaboration with Shell as well as coring for the EU funded Blue Mining project.

Sonar and Visual Survey
Visual survey can be challenging using traditional underwater cameras due to limited light and potential for low visibility. Laser survey offers some advantages especially for high resolution over reasonably short distances. Sonar systems can overcome low visibility issues, but often deep water has low turbidity, which if the area is illuminated visual survey may be quite adequate.

Coda Octopus
Coda Octopus produces a range of real-time 3D sonar systems including the Echoscope®. The Echoscope® is a unique sonar which through patented technology enables the generation of real time 3D images on their operating and survey software Underwater Survey Explorer.

The UK Supply chain has a particular strength in both the field of prospecting - the offshore activity, but also in the interpretation of that data. This is a very significant opportunity for our survey and seismic compnaies to diversify and position themselves as the "go to" source for such expertise. The recovery of samples for analysis and evaluation plays strongly into the capability of the UK supply chain. Many companies make soil coring (drilling) devices and ROVs and AUVs complete with manipulator arms for the performance of a variety of tasks is an area in which the UK excels.

Fugro
Fugro provides large-scale, detailed, calibrated geologic mapping and integrated high resolution seafloor mapping and object detection in deep water in remote areas of the planet. Fugro employs a large fleet of modern geophysical research vessels, seabed drills, custom-built work class ROVs, and AUVs. Sensors on these platforms include combinations of: multibeam echosounders, water column chemical and particle samplers, magnetometers and other electromagnetic sensors, 3-D high resolution seismic; cameras, laser imagery, seafloor imaging sonars, and sediment profilers.

Fugro has conducted numerous geotechnical investigations for deep sea mineral prospecting purposes, notably in and around Korea, Papua New Guinea, Japan and China. Fugro's vessel-based drills and robotic Seafloor Drills (SFD) are capable of operating in depths of over 3000 m.

Fugro has developed geophysical analysis techniques for reservoir identification and specialized tools for collecting and preserving methane hydrate samples at in situ pressures. To date, Fugro has provided the drilling vessels, well logging, coring, or science party to 16 of 20 of the world's major methane hydrate field expeditions to quantify the magnitude of gas hydrate deposits. Fugro has designed, manufactured and operated geotechnical drilling equipment for the Japanese government which could play an important part in pilot gas hydrate mining tests currently being planned.

4.4 SEA MONITORING

It is important to consider sea monitoring during mining operations; plume dispersion, movement of sediment and changes to the local ecosystem need to be regularly assessed to determine their impact. Several technologies can be used for sea monitoring such as ROVs and AUVs. These vehicles can have sensors installed in order to perform a variety of tasks such as multispectral imaging, light and noise monitoring and visual survey.

Frequent surveys can be carried out both during assessment and operational stages. The data gathered from these surveys must be effectively analysed for the impact of subsea mining to be quantified.

HR Wallingford
HR Wallingford plans, implements and supervises marine surveys in challenging conditions during the assessment and operational stages. These include: topographic, bathymetric and hydrological surveys; meteorological and oceanographic surveys; sediment transportation and morphological analysis, and sediment release during marine mineral dredging and processing operations.

With an active programme of research, HR Wallingford is also seeking to further enhance understanding of the management of environmental risks stemming from the physical disturbance of the seabed by mineral recovery operations. HR Wallingford is part of MarineE-Tech. HR Wallingford's role includes field measurements of the dispersal of sediment plumes such as might be generated by mining activities. These measurements include deployment of HR Wallingford's benthic observatory.

Marine Ecological Surveys Limited (MESL)
MESL is able to offer marine environmental consultancy support for the full lifespan of deep sea mining operations. This ranges from the data gathering and environmental scoping stages of a project, to impact assessments, marine survey services and sample analysis, through to postoperative monitoring, reviews and seabed recovery assessments.

Plymouth University
The Plymouth University Marine Resource Management research group have advanced experience in seabed characterization and quantitative biodiversity assessment, particularly using remote camera technology. They study the impact of human activity on seabed ecosystems and monitoring recovery. They have also conducted long term studies monitoring the effectiveness of marine protected areas and their impact on biodiversity, fisheries and socio-economic measures.

Coda Octopus
The Coda Octopus Echoscope has been used in subsea mining operations, both deep water and shallow water projects. During mining operations, suspended solids in the water may present low visibility conditions, this means the information from standard underwater cameras is of little value. Japan Oil, Gas and Metals National Corporation (JOGMEC) use the Echoscope mounted on their mining vehicle to visualise the subsea mining area during mining operations.

Fugro
Fugro has extensive experience of conducting marine environmental monitoring from multiple platforms including vessels, ROVs, AUVs, deep water buoyed monitoring systems and seabed landers. Monitoring techniques include noise and plume

measurements, and geophysical, physio-chemical sediment and benthic fauna resurvey to assess impacts and changes to deep sea ecosystems.

Fugro also acquires metocean data worldwide and can provide critical buoy monitoring and metocean forecasting services and metocean design criteria to support safe mining operations.

4.5 VESSELS

Vessels are required at all stages in a typical subsea mining life cycle, from exploration and research vessels to production support vessels. In the case of exploration and research, ROVs or AUVs will often need to be launched, piloted and recovered from these vessels. For production support vessels there will need to be sufficient deck space for ore processing and offloading as well as mining machine support.

The UK has a proven track record of subsea operations using various vessel types from dive support vessels to barges. The UK marine equipment manufacturers, operators and service companies offer design, manufacturing and service solutions for several industries including; oil and gas, offshore renewables and defence. Many of the world's leading marine and industry research and training institutions, manufacturers and service providers are based in the UK.

Marine Ecological Surveys Limited (MESL)
MESL is a part of the wider Gardline Group. Gardline operates a fleet of research vessels globally across a broad range of marine industries at all water depths. Using these vessels, Gardline offers a range of services including hydrographic, geophysical, environmental, oceanographic and marine wildlife surveying, and data analysis and reporting MESL's sister company, Marine Planning Consultants (MPC), also provide environmental impact assessment services and licensing support.

National Oceanography Centre (NOC)
NOC's research vessels support complex, multidisciplinary, multi-investigator research, and include state of the art technology and instruments to provide research needs across all the disciplines.

The ships are built to carry out oceanographic research in the most extreme and remote oceanic environments on planet Earth. The high-tech instruments and scientific facilities are capable of producing both precise and accurate data for a wide array of oceanographic parameters. The data collected by the research vessels help NOC scientists to lead the way in oceanographic science by enabling them to make models and predictions about the oceans and how they may change in the future.

Fugro
Fugro operates an industry-leading fleet from the UK that comprises modern deep sea geophysical and geotechnical vessels, subsea construction vessels, ROVs, AUVs, and seafloor drills dedicated to marine site characterisation. These vessels operate across the globe in deep water environments. Fugro provided the vessel platforms for Nautilus Minerals' massive sulphide exploratory drilling and sample collection in Papua New Guinea in 2010- 2011, and the large construction support vessel for the work class ROV-based exploration campaigns in 2009.

Fugro designs and builds many of its survey platforms, including work class ROVs and drill rigs. Fugro's in-house engineering expertise allows the creation of bespoke solutions which combine cutting edge sampling/testing equipment with multi-purpose vessels, including the installation of tailored equipment onto specialist platforms.

4.6 LEGAL AND FINANCIAL

Although governance in the deep ocean is fragmented, outside of EEZs the United Nations Convention of the Law of the Sea (UNCLOS) is the framework for international ocean management. The International Seabed Authority has developed the draft 'Mining Code' which is a comprehensive set of rules, regulations and procedures issued by the ISA to regulate prospecting, exploration and exploitation of marine minerals in the international seabed area.

The framework for financing and development of a subsea mining project will involve a complex set of agreements which will be subject to various governing laws. Privately funded subsea mining projects have struggled with finance, this may be a continuing trend until return on investment can be proven with an established commercial mining operation.

Other business aspects that are yet to materialise, but will be necessary concerns for the industry to mature are: insurance, the management of waste and the degree of local content employed in any given project / mine.

What might be pivotal to the success or otherwise of subsea mining is how as an industry public relations are handled. Ultimately society will determine the acceptability of subsea mining. It will come down to the trade off of society's needs for these materials versus the environmental impact. Incorrect management of communications could impair the industry's future success regardless of whether the science supports the exploitation of the ocean's resources.

Marine Ecological Surveys Limited (MESL)
MESL has played a critical role in helping to develop the scientific knowledge-base that underpins the regulatory principles and processes governing extractive marine projects around the world.

National Oceanography Centre (NOC)
The NOC acts as an interface between legal and technical aspects of marine policy making and implementation.

Plymouth University
Plymouth University's Environment and Marine Law research group work on a number of legal issues relevant to subsea mining including environmental impact assessment and waste management regulations. Ongoing work is looking at the sustainable use of areas beyond national jurisdiction under the UNCLOS.

Seascape Consultants Limited
Seascape Consultants is a UK business that provides a range of services to the offshore and marine sector focusing on sustainable environmental management and development. Seascape Consultants specialise in the provision of high-level advice to the marine sector. Their expertise include translation of scientific results to policy, stakeholder consultation and engagement, ocean governance issues and the management of marine data and information. Seascape is currently engaged in consultations on the draft Regulatory Framework for Mineral Exploitation in the Area (Environmental Matters), which was published by the ISA in January 2017. This process will feed into the draft mining code to control mineral exploitation in the Area.

SMD
SMD is an active participant in the development of regulatory frameworks and research into sustainable management of the EU's subsea resources.

Fugro
Fugro has contributed to the development of best practice for deep sea mining environmental survey and impact assessment through its scientific research within the MIDAS and VAMOS projects. Fugro continues to contribute to relevant consultations to develop regulatory frameworks.

5. UK AGENCIES AND BODIES

Department for International Trade (DIT)
The Department for International Trade is the government department that helps UK-based companies succeed in the global economy. They also help overseas companies bring their high-quality investment to the UK's dynamic economy, acknowledged as Europe's best place from which to succeed in global business.

National Subsea Research Initiative (NSRI)
NSRI is the research arm of Subsea UK. It has been set up to bring academia and industry together to collaborate on getting technology to market much more quickly. NSRI is the focal point for the co-ordination of research and development activities for the UK's subsea sector.

Subsea UK
Subsea UK is the industry body and focal point for the entire British subsea industry and aims to increase business opportunities at home and abroad for the sector. Subsea UK act for the whole supply chain bringing together operators, contractors, suppliers and people in the industry. Subsea UK was established by the industry and acts on behalf of the industry. Subsea UK champion Britain's subsea sector, which leads the way globally in terms of market size, experience and technology development.

Mining Association of the United Kingdom

The Mining Association of the United Kingdom is a trade association for all kinds of mining undertaken by UK companies. It promotes and fosters the interests of the metals and mining industry in any part of the world and the corporations, companies, firms and persons engaged or interested in the industry or in industries ancillary to or allied with the metals and minerals industry.

Its members include all the major industrial mineral mining operators in the United Kingdom. Its work is concentrated on representing its member's interest at Government and European level on environmental and health & safety issues. It is actively involved in lobbying and consulting on proposed legislation.

Association of British Mining Equipment (ABMEC)

The Association of British Mining Equipment has a history dating back almost 100 years. Its role as an Association is to provide a service to its members in order to help promote sales, growth and gather market intelligence.

Institute of Materials, Mineral and Mining (IOM3)

The Institute of Materials, Minerals and Mining (IOM3) is a major UK engineering institution whose activities encompass the whole materials cycle, from exploration and extraction, through characterisation, processing, forming, finishing and application, to product recycling and land reuse. It exists to promote and develop all aspects of materials science and engineering, geology, mining and associated technologies, mineral and petroleum engineering and extraction metallurgy, as a leading authority in the worldwide materials and mining community.

6. CONCLUDING REMARKS

The UK has an array of expertise and supply chain capabilities for subsea mining. The continuous research and development will only strengthen this offering as the subsea mining industry continues to grow. The involvement of UK organisations in European Union funded programmes has put these organisations at the cutting edge of the industry.

For further information about the organisations outlined in this document, contact details are available on pages 21-22.

To find out more about UK based companies working in this industry, visit the NSRI matchmaker (http://matchmaker.nsri.co.uk/) The NSRI Matchmaker service aims to partner end users with technology researchers and developers in the appropriate fields. Organisations working within the subsea industry can add their details to matchmaker order to demonstrate development activities and capabilities.

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